TECHNOLOGY

for

SUGAR REFINERY
WORKERS

by

OLIVER LYLE

with
93 Illustrations
by the Author

Out of the strong came forth sweetness.
Judges XIV 14.

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Content if hence th'unlearned their wants may view.
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Look here, upon this picture, and on this.
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LIST OF TABLES

My tables—meet it is I set it down.
SHAKESPEARE—Hamlet—1601

FOREWORD.

For out of the old fieldes, as men saithe,
Cometh al this new corne fro yere to yere,
And out of old bookes, in good faithe,
Cometh al this new science that men lere.

CHAUCER—Canterbury Tales—1389

Technology means the Science of an Art or Craft. In Sugar Refining we practise many arts and crafts. There are many men, foremen, staff and workmen who want to know what it is all about. Why certain things must be done and certain things must not be done. This book is an attempt to explain these things. It does not seek to describe sugar refining nor to teach any man his job. It is an endeavour to make the understanding of sugar refining more clear ; to explain some of the things we are continually doing in the refinery and why we do them ; to explain various pieces of plant, their working, and why we use particular plant in particular places ; to explain heat and electricity ; to explain the tests used to measure the success of each part of the process, why such tests are necessary and how they are carried out ; to explain the economy of the factory.

The greater the understanding of these things the greater will be the satisfaction in the day's work. If a man knows what Brix, Pol and pH really mean, he is more likely to look upon the Laboratory as a place where help and guidance can be obtained than as a smelly den of interfering busybodies. If the workings of pumps and motors are really understood it enables the best to be got out of them.

The descriptions of technical matters have not been copied out of text-books. The author has tried to remember all the difficulties that beset him when he was learning science. He believes that some things, (for example " acceleration " and " the heating effect of electricity,") have been described in an understandable way, whereas the descriptions in many text-books leave the student confused.

Most of the illustrations were added after the main text had been written. These carry their own descriptions, which are printed in *italics*. The main part of the text contains no reference to these illustrations. It is hoped that by explaining things twice over in this way the reader's chance of understanding will be increased.

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Familiar things have not been illustrated, nor have things like centrifugal machines or filter presses whose construction can be seen by going and looking at them. To divide off the illustration-descriptions from the main text, asterisks, in the form of sucrose crystals, have been used.

Many of the illustrations are diagrams. A picture may show a thing happening, but it does not necessarily show how or why it is happening. A diagram, on the other hand, tries to show just how or why the thing is happening, but makes no pretence at showing a life-like picture of the occurrence. A comparison of Figures 4 and 5 on pages 22 and 23 will make the difference between picture and diagram quite clear.

Some of the things described in the book are difficult to understand and the descriptions are unfortunately not good enough to ensure understanding after just one reading. The reader is asked not to be disappointed if understanding does not take place at the first reading. The book is patchy. Some things are dealt with in much detail, other things are dealt with very briefly. It is hoped that the selection of subjects treated fully has been fortunate.

The book would never have been finished had it not been for the encouragement and help, criticism and correction that the author has received from many T. & L. colleagues, especially from Peter Runge, and from Philip Lyle, J. O. Whitmee and F. M. Chapman.

The author wishes also to thank the following gentlemen:— Sir William Bragg, O.M., D.Sc., President of the Royal Society, for permission to paraphrase his analogies of the refraction of light in Chapter 2 ; Mr. Sydney W. Cole, M.A., of the Biochemical Institute, Cambridge University, for his help with the physiological aspects of the sugars, in Chapter 17 ; and Mr. J. A. Vice, A.M.I.E.E., and Mr. F. C. Sellens, A.M.I.E.E., of the County of London Electric Supply Co. Ltd., for their reading and correction of Chapters 5, 6, 7 & 8.

There is far too much mention of Plaistow Wharf. This is regretted, but it just could not be helped. The book was written primarily for the Plaistow Wharf staff.

Much of the book was written and many of the illustrations made during air-raids, providing welcome occupation and distraction. This is largely the reason for the appearance of the book at this otherwise unsuitable time.

1941.   **O. L.**

TECHNOLOGY FOR SUGAR REFINERY WORKERS.

Please make the following corrections.

Page 46   1st word : " refraction " should read " reflection."
- 72   The Polariscope, 7th line : ⎫ " German " should read
- 75   Last line.   ⎭   " Scotsman."
- 152   1st line of middle paragraph : " Fig. 41 " should read " Fig. 44."
- 162   4th line from bottom: "Fig. 41" should read "Fig. 44."
- 164   11th, 14th, 16th ⎫ " Fleming's rule."
      and last lines : ⎬   should read
- 165   Last line :   ⎭ " the polarity rule—p. 122."
- 212   Supersaturation at Different Stages, 5th line : " the next page " should read " this page."
- 240   10th line from bottom : " page 204 " should read " page 205."
- 241   12th line : " page 204 " should read " page 205."
- 241   B.P.E. in Third Body in Table: "1.5" should read ".5"
- 248   Sweetening off, 4th line : " over 1% " should read " about 1%."
- 253   9th line from bottom : " page 204 " should read " page 205."
- 253   7th line from bottom : " page 236 " should read " page 237."
- 254   3rd line : " Chapter 17 " should read " Chapter 15."
- 256   11th line from bottom : " page 248 " should read " page 245."
- 335   Payment of Duty, 3rd paragraph, 5th line : " analysed " should read " ascertained."

CHAPTER I. SUGAR.

The sweetest thing that ever grew
Beside a human door.

WORDSWORTH—Lucy Gray—1799.

Sugar—The Occurrence of Sugar in Nature—The Sugar Cane—Manufacture of Raw Cane Sugar — The Sugar Beet — Manufacture of Raw Beet Sugar—Comparison of Cane and Beet Extraction Methods—Sugar Refining.

The main text of this chapter contains no reference to the illustrations, which carry their own explanations, printed in italics.

SUGAR.

Sugar is one of the large group of substances which are called by the chemists " carbohydrates." There is no need to worry about the chemical composition of sugar nor about the hundred or so different sugars known to the chemist. There are only two kinds of sugar that we are concerned with in sugar refining, namely : " Sucrose," the white sugar that we use in our food and drink, and " Invert " sugar that we find in fruits and honey.

Invert sugar comes to us in small quantities in all raw cane sugars and it is formed in spite of all our precautions in certain parts of our process. Invert sugar turns brown very easily when heated or when air is mixed into a solution containing it. It is very difficult to produce invert sugar in a quite dry state, so that, although it is a little sweeter than sucrose, we look upon it as one of our enemies. But it is an essential ingredient of golden syrup and of the syrup which is left adhering to soft sugars such as pieces.

Sucrose will turn into invert sugar very easily and we can make invert whenever we like, but it is impossible for us to do what many plants and trees can do, namely, turn invert sugar into sucrose.

Invert sugar actually consists of a mixture of equal parts of two sugars called " dextrose " and " lævulose." They are sometimes also called " glucose " and " fructose."

As a food sucrose is very readily and easily absorbed by our digestive organs. It is an energy producing food and is a necessary

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part of the diet of growing children and of those doing hard muscular work. Owing to its small bulk and easy quick absorption it is very useful to those about to undergo an ordeal—athletes before a race ; hospital patients before an operation. Experiments have shown that, on an empty stomach in cases of exhaustion, improvement occurs as quickly as five minutes after eating sucrose.

THE OCCURRENCE OF SUGAR IN NATURE.

Sucrose, the ordinary sugar of the household, occurs widely distributed in the vegetable kingdom. It is found in the roots and stems of all grasses, in such roots as parsnip, carrot, turnip and beet, and in the sap of many trees, notably the sugar maple and many palm trees. The juices of most fruits contain sugar, the amount present varying with the ripeness.

In all these plants the presence of sugar is due to an action in the leaves brought about by sunlight in the presence of the green colouring matter of the plant by which carbon dioxide—CO_2—from the air combines with water to form sugar. (Quite recently this combination has been made to take place artificially in the laboratory of Liverpool University by Professor Baly.) The sugar travels in the sap of the plant from the leaves to other parts where it is stored for use for future growth. In the sugar cane it is stored in the stem and in the sugar beet in the root. Although many plants contain quite a lot of sugar, the commercial production in large quantities is only possible at reasonable cost from the sugar cane and the sugar beet. Sugar cane is grown in very hot countries ; sugar beet in temperate countries.

THE SUGAR CANE.

Raw cane sugar comes to Great Britain chiefly from Cuba, British West Indies, Australia, Natal, Mauritius, Demerara, Peru, Java, San Domingo and Brazil. Other cane-growing countries are India, Egypt, U.S.A., Central America, Fiji, Ecuador, Venezuela, The Philippines, Hawaii, Mozambique, Formosa and China.

The sugar cane is a gigantic grass, and consists of roots, stalk and leaves. The stalk is made up of segments each from three to eight inches long and is like a bamboo. It reaches a height of eight to fifteen feet, though some kinds grow as tall as twenty feet. The stalk is from half an inch to two inches in diameter. Long narrow leaves grow in two rows from sheaths round the stem joints. As the cane grows the lower leaves die and fall off. The leaves are from three to five feet long and two or more inches wide. The stalk is a tube of hard rind filled with softer fibre. The inner fibre contains the sugar.

Fig. 1
Growing Cane.

The sugar cane grows from ten to twenty feet high, depending on the variety and on the country in which it is growing. The stems vary from half an inch to nearly two inches in thickness. The stems, which are encased in a hard rind, contain the sugar. Leaves about three or four feet long grow in two rows from the stem joints. As the cane grows the lower leaves die and fall off. The canes take from eight to twenty months to ripen. The roots left in the ground after the canes have been cut will grow new canes several times before replanting is required.

When the cane is ripe it produces at the top of the stalk a feathery plume of grey flowers called the " tassel," from two to four feet long. The length of time required for the cane to ripen and the time for harvesting vary with the different kinds of cane and the different countries in which it is grown. The usual time for ripening is from nine to fourteen months, and harvesting is going on at all times in the year somewhere in the world.

As far as the cane planter is concerned the cane is ripe when it contains the greatest amount of sucrose. Before ripening there is quite a lot of invert sugar present, and if the ripe cane is left standing for long the sucrose changes into invert. It has been explained on page 15 that invert sugar is undesirable, so it is important that the cane should be harvested when the invert is as low as possible, which is also when the sucrose is as high as possible. In some countries, such as Brazil, the cane always contains a lot of invert which often makes Brazilian sugars difficult to refine. In some countries, such as Natal the climate does not suit ordinary cane. These countries have long, hot, dry spells and a special kind of cane—the Uba cane—has been found to be particularly suitable to withstand these dry periods. As a protection against drying up the Uba cane has a coating of natural wax on it, and it is this wax which causes sugars from the Uba cane to be difficult to refine.

When ripe, the canes are cut down near the ground and the green tops and the leaves are cut off. The canes are cut up into lengths of about four feet and sent to the factory by bullock-cart, mule wagon, tractor or railway.

Part of the cane stalk near the top is cut off at harvest and used for planting for new canes. There is a little bud or eye at each joint which throws out a new cane when the piece is planted. The old stumps which are left in the ground will grow new canes, called ratoons, a number of times before it is necessary to plant afresh.

The sugar content of ripe cane is about 14% to 17% and the yield of sugar per acre of land is from 4 to 8 tons, depending on the country and the amount of money spent on irrigation, etc.

This picture shows, full size, a piece of cane of the variety called Bourbon. The Bourbon cane has been cultivated for some 150 years and has probably produced more sugar than any other variety. It was introduced into the West Indies from the Indian Ocean Island of Bourbon. The Bourbon cane will grow in great profusion. It has in favourable conditions produced over 12 tons of sugar from one acre. The juice from the Bourbon cane is very pure and has a high sugar content, but the cane is very sensitive to drought and is liable to catch diseases easily. Most of the great disasters in cane crops due to disease have occurred in Bourbon cane. For this reason it is rapidly being replaced by some of the new canes which have been produced by cross-breeding in which a high sugar content and a pure juice are combined with a much greater resistance to exceptional weather and a greater immunity from diseases.

Fig. 2
Bourbon Cane.

This picture of a piece of Uba cane is full size. The Uba cane is very robust and hardy. It has a coating of wax on the rind which helps it to withstand long dry periods. It is very healthy and does not catch diseases easily, but the sugar content is low, and raw sugars made from it are difficult to refine. Uba cane will probably soon be replaced by some of the new cross-breed canes which combine hardiness with good sugar content. The little buds at the joints will be noticed. It is from these buds that new canes grow when a piece of cane is planted. Nowadays hardly any names are used for cane varieties ; canes are given code numbers referring to the time and place where they were bred.

Fig. 3
Uba Cane.

MANUFACTURE OF RAW CANE SUGAR.

When the canes reach the factory—sometimes called " mill " or " central "—they are tipped on to a conveyor or elevator which takes them to the cane-crushing mill where the juice is squeezed out. The cane mill consists of two parts : the crushing rollers and the squeezing rollers. The crushing rollers are arranged in pairs and the squeezing rollers in threes—one at the top and two at the bottom. The rollers are about three feet in diameter and about seven feet wide. The crushing rollers are provided with zig-zag corrugations roughly diamond shaped to break up the rind. The squeezing rollers are grooved to grip the cane and to allow passageways for the juice. The bearings which carry the rollers are able to slide and the rollers are pressed together by hydraulic pressure so that each top roller exerts a pressure of about 500 tons on the lower rollers. There are often two sets of crushing rollers and sometimes as many as five or six sets of squeezing rollers. The whole mill is called a " tandem."

In order to extract as much sugar as possible, water is sprayed on to the crushed cane as it passes into the last set of rollers. The sweet water squeezed out in this set is pumped back on to the cane entering the last but one set and so on. The amount of water sprayed on must be adjusted to be the least possible as it all has to be evaporated later. The amount must be a balance between the value of the extra sugar extracted and the cost of evaporation.

A good modern tandem can crush over 3,000 tons of cane in twenty-four hours, needs about 1,500 horse power to drive it and can extract about 97% of the sugar in the cane.

The juice from the tandem contains about 11% of sugar, about 2·5% of impurities and the rest is water.

The juice is limed and heated which causes many of the impurities to collect together when they can be skimmed off as a scum or allowed to settle as a sediment. The juice then goes to the evaporators to be thickened up.

The cane mill or "tandem" consists first of crushing rollers which break up the hard cane rind. The tandem in this picture has two pairs of crushing rollers, which are provided with zig-zag corrugations to help to break up the rind. The uncrushed cane, which has been already cut into lengths of about four feet, can be seen in the picture entering the first pair of rollers at the far end of the tandem. After passing through the second pair of crushing rollers the cane goes on to the squeezing rollers which are arranged in threes, two at the bottom and one at the
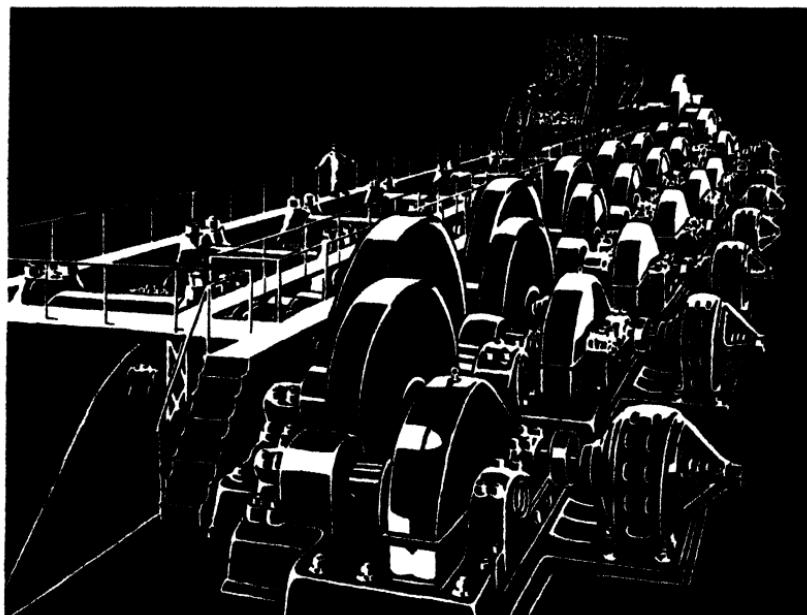
Fig. 4
Electrically Driven Tandem.

top. There are six sets of squeezing rollers in this tandem. The top roller of each set can be clearly seen. The driving motors and the triple reduction gears are on the right. A tandem such as this can crush over 3,000 tons of cane in twenty-four hours, uses about 1,500 horse power and can extract about 97% of the sugar in the cane. After the biggest paper-making machines, a big tandem is about the next largest machine in use in industry.
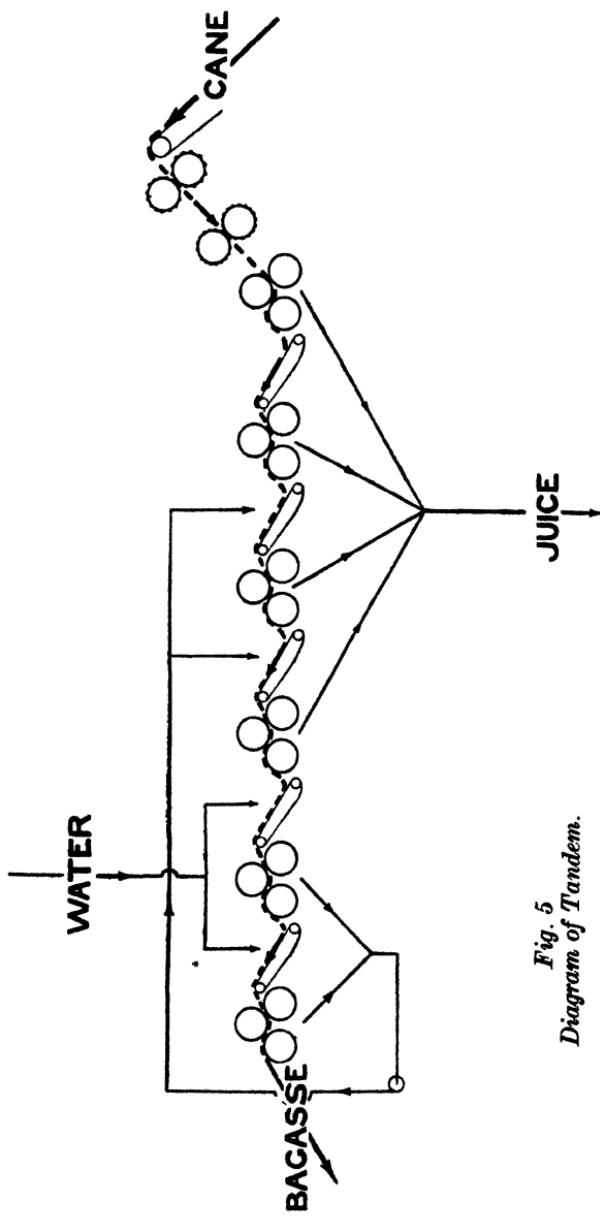
Fig. 5
Diagram of Tandem.

The last picture showed a large cane mill or tandem. It did not really show very much of the way in which the cane passed through the rollers. The figure shown above is a diagram of this same tandem. The thick dotted line shows the path of the cane. Before the cane reaches the tandem it has already been cut into suitable lengths of about four feet. It is brought in by the elevator on the extreme right. It then passes through two sets of crushing rollers which are corrugated to break up the rind. Having been crushed into small fragments it next goes through six sets of squeezing rollers. Five short conveyors transfer the crushed cane from one set of rollers to the next. Water is sprayed on to the crushed cane before it enters the last two sets and the sweet water squeezed out by them is pumped back on to the middle sets.

The thin juice is thickened up, that is to say much of the water is boiled off it, in multiple effect evaporators. A description of multiple effect evaporation will be found later on in the book. It is then sent to the vacuum pans—which are also described further on—where the sugar is boiled out in the form of crystals. The mixture of crystals and syrup which is dropped from the pans is called a " massecuite " (French for cooked mass) and is put into centrifugal machines where the syrup is spun off the sugar crystals. The syrup from the centrifugal machines is returned to the vacuum pans where another crop of sugar is boiled from it. The resulting massecuite is also put through centrifugal machines and the syrup thrown off is again returned to the pans for a third and last crop of sugar to be boiled off it. The syrup thrown from this third massecuite is " molasses "—that is a syrup from which it is impossible or uneconomical to obtain further sugar by boiling.

The sugar from the centrifugal machines is bagged in heavy jute bags and sent to a port to await shipment to a refiner.

The exhausted cane fibre, called " bagasse " or " megasse," is burnt in special furnaces under the boilers to make steam for generating power and for pan boiling, evaporating and other process purposes.

THE SUGAR BEET.

The sugar beet is grown in the northern part of North America and in most European countries. Beet sugar production has been almost entirely due to war or to the fear of war. Napoleon, unable to obtain sugar for France owing partly to the British blockade and to the fact that he had prohibited the import of products of the British Empire, gave great assistance to the beet producers and virtually founded the industry. This was the beginning of a great wave of beet production on the Continent. After the Kaiser's War various British governments gave generous financial aid to the producers of beet sugar in Great Britain, with the result that in 1938 some 500,000 tons were produced in Great Britain. Beet sugar cannot compete with cane sugar on level terms. The basic reason why this must be so is simply that sugar is made in the plant by sunlight and a plant which will grow easily in the tropics must have a tremendous advantage over one that has to try to grow in our miserable climate. The best yield of beet sugar per acre is 2 tons,

whereas 4 to 8 tons per acre is normal for cane. The beet crop requires more attention than a cane crop, and the cost of labour in beet-growing countries is a great deal more than that of the dark-skinned cane labourers, whose wants are so much simpler. There is no reason for beet sugar production in any country except to ensure a supply during war. The beet sugar industry in every beet-growing country receives financial assistance in some form or other to enable it to compete with cane sugar.

Beet is grown from seed sown in the spring. When the young plants are a few weeks old they are thinned out until they are spaced about a foot apart. Constant hoeing is required to keep down weeds and to aerate the soil. The beets are ripe, that is to say, contain the greatest amount of sugar about the end of September. The beet does not deteriorate much if left in the ground, but the harvest must be gathered quickly lest frost prevent the beets being pulled at all. The knowledge that short days and bad weather lie ahead causes most farmers to gather their beets early, so that some have to be stored. Once beets are picked they do deteriorate. The factory therefore has to deal with its crop in the shortest possible time. A beet factory generally works for about three months. This is another reason why beet sugar is more costly to produce than cane sugar. A cane mill usually works for about five months or more. Therefore for a given amount of sugar production a cane factory need only be a little more than half the size of a corresponding beet factory.

The sugar beet has a long tapering root. About six inches below the surface of the ground the main root sends out long thin rootlets to gather nourishment from the surrounding soil. The main root and its subsidiary rootlets occupy a cylinder of soil about a foot in diameter and extending sometimes as much as five or six feet down into the ground. An average beet is about three inches in diameter at the top end just below the leaves and its useful length is about seven or eight inches. At harvesting time the soil round the root is loosened and the root pulled out. The long tap root contains very little sugar and is left in the ground where it decomposes and acts as a useful fertiliser for future crops. The top of the beet near the leaves is also poor in sugar and is cut off in the field. The tops and leaves are collected and used for feeding cattle. The beet as delivered to the factory weighs about $1\frac{1}{2}$ lb. and contains about $\frac{1}{4}$ lb. of sugar.

Ground that has been growing beet one year cannot grow a satisfactory second crop of beet for three or four years, but must be sown with some other crops which derive much benefit from the deep ploughing, manuring, etc., which has been expended on the beet crop.

MANUFACTURE OF RAW BEET SUGAR.

The beets on arrival at the factory are weighed and sampled and tipped into large concrete silos which have a "flume," or narrow channel of running water at the bottom. The running water conveys the beets to the elevator at the factory wall. The water, in addition to conveying, does good service in washing stones and mud off the beets. At the discharge of the elevator the beets pass through weed catchers and beet washers to the picking tables where stones, bits of wood, etc., are removed by hand. They then pass to the slicing machines where corrugated knives cut them into shreds or " cossettes " about three inches long, a quarter of an inch wide and an eighth of an inch thick.

The slices or cossettes are filled into tanks, ten to sixteen of which form a "diffusion battery." Water passes through these tanks, being added fresh to the oldest—that is the tank containing the oldest slices. It then passes through a heater and on through the next tank and so on through the whole battery until it finally passes through the last or newest tank which contains the fresh slices. By this arrangement the slices which are richest in sugar come first in contact with the water which is richest in sugar, while the slices which have had nearly all their sugar extracted receive pure water which will remove almost the last trace of sugar. When the extraction of the sugar in the beet slices in the first tank is complete the water is shut off this tank and is put on to the next. The exhausted slices or " pulp " is emptied out and the tank is filled with fresh slices. This tank now becomes the last in the battery receiving juice from the tank which had hitherto been the last. In this way the greatest amount of sugar is extracted with the least amount of water.

This " diffusion " process has one great advantage over the cane-crushing process, namely that by its means many undesirable impurities are left behind in the pulp instead of being brought into the juice. The reason for this is that the thin walls of the cells which make up the root will readily pass water in one direction in exchange for crystallisable solids, for example sugar, which pass out ; whereas gums and waxes and other impurities do not readily pass through the cell walls but remain in the pulp. This exchange through the membrane of the cell is called " osmosis." Were the beet juice extracted by squeezing, the cells would have their walls broken and there would be no beneficial discrimination in favour of sugar.

The exhausted pulp from the diffusion battery is squeezed to remove much of the surplus water and is either sold wet as cattle food or dried and stored and sold later for the same purpose when it is often mixed with molasses.

The beet juice is a dark grey-brown liquid containing about 13% to 15% sugar, about 2% to 3% of impurities and the rest water.

Milk of lime is added to the juice and carbon dioxide gas—CO_2—is bubbled through. The gas is obtained from the lime kiln where limestone, a hard form of chalk, is burnt to make the lime used for adding to the juice. The gas combines with the lime to form a precipitate or powder of chalk which entangles most of the gummy matters and some of the colour. This process is called " carbonatation " and is described in more detail further on in the book.

The juice is then filtered when the chalk with the entangled impurities is removed. After filtering, the juice is again gassed with a further removal of impurities by filtration. The clear juice then goes to a multiple effect evaporator where it is thickened up. The thick juice is boiled in vacuum pans and the sugar is separated from the syrup in centrifugal machines. The syrup from the machines is reboiled until a molasses is made which will yield no more sugar.

COMPARISON OF CANE AND BEET EXTRACTION METHODS.

The diffusion process used for extracting the sugar from the beet can also be used for extracting sugar from cane. The diffusion method extracts the greatest amount of sugar with the least amount of impurities. On the other hand it does not extract quite so much sugar and the juice contains a little more water. There are also two other reasons why it is not used for cane. The first is that great difficulty is found in keeping the knives sharp when they have to cut the very hard cane rind. The other is that the cane mill is generally dependent on bagasse for fuel. The milled bagasse is a good fairly dry fuel which burns well. Bagasse from a diffusion battery is saturated with water and requires drying, after which it powders easily and does not burn well. The beet factory does not use the squeezing process because the beet contains more undesirable impurities than the cane and these would be squeezed into the juice. The beet pulp has a very poor fuel value and cannot compare with coal which can usually be obtained by a beet factory at not too high a cost as beet factories, unlike cane factories, are generally situated near coalfields.

The sugar beet grows in temperate climates.   It cannot compete on level terms with the sugar cane as far as cost of sugar production is concerned because sugar is made in plants by sunlight.   The root of the beet is about six to eight inches long and about three inches across.   The average root contains about $\frac{1}{4}$ lb. of sugar.   The green tops are cut off and used for cattle food as they contain very little sugar.

Fig. 6
The Sugar Beet.

The beet crop requires a great deal of agricultural work, and is therefore of great benefit to subsequent crops because beet cannot be grown more than once every three or four years on the same land.   The long rootlets, often three times as long as is shown in Fig. 6, are left in the ground where they decay and act as manure for the following crop.

SUGAR REFINING.

The first process is called " affination," a French word which means refining. The process consists of mixing the sugar with a syrup to soften the film of adhering molasses and then washing off as much of this adhering impure molasses as possible in centrifugal machines.

The syrup which is washed off contains a good deal of sugar, which was dissolved by the wash water, and is boiled in vacuum pans to recover as much of this sugar as possible. This requires three boilings before the final syrup is molasses, that is a syrup from which no further sugar can be economically extracted. This process is called " recovery."

The washed raw sugar and the several sugars from the recovery process are dissolved or " melted " in water and filtered to take out sand, mud, bacteria, insects, cane fragments, gums, waxes, etc. The bright filtered liquor is then passed over char—a charcoal made by partly burning bones—to remove the colour and much of the dissolved impurities.

The fine white liquor from the char is boiled in pans to make white sugar which is washed in centrifugal machines. The sugar is dried in granulators and sieved to remove lumps and dust and then packed.

The syrup from the white sugar centrifugals is again run over char and reboiled for white sugar several times until the impurities in the syrup have become so concentrated that a white sugar can no longer be produced. Pieces, or yellow sugar, is then boiled out of it, or it is partly inverted and turned into golden syrup. The final syrup from the pieces boiling is sent to the recovery house where the last available sugar is boiled out of it leaving molasses.

CHAPTER 2. MEASUREMENT.

For hot, cold, moist and dry, four champions fierce,
Strive here for mastery.

MILTON—Paradise Lost—1666.

The main text of this chapter contains no reference to the illustrations, which carry their own explanations, printed in italics.

REASONS FOR MEASUREMENTS.

It is necessary to have a clear understanding of the various ways in which each part of the sugar refining process is measured. Sugar refining consists of a series of separations, each separation leaving a purer product to go on to the next process.   It is necessary to take frequent measurements of the purity of the product. Actually we find it much better in convenience and accuracy to measure the impurities.   In this way we can watch the most important impurity in the particular circumstances.   The sugar industry as a whole measures and talks about purity.

All the refining operations are carried out with the sugar in a wet state, either as a solution—" liquor " or " syrup "—or as a mixture of crystal sugar with syrup—" massecuite " or " magma." Generally speaking we use the word liquor to mean a sugar solution from which no sugar has been removed by boiling, whereas a syrup is a solution that has been thrown off sugar in a centrifugal machine. A massecuite is a mixture of sugar crystals and syrup which has been produced by boiling the crystals out of the syrup.   When we speak of a magma we mean a mixture of crystal sugar and syrup which has been made by mixing the two together.   As our final product is dry white sugar it will be necessary to remove all the water from our liquors and syrups, and this can only be done by

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burning coal. An accurate measure of the water present in any liquor or syrup is therefore important.

Very few operations can be carried out cold. But as heat causes sugar, particularly invert sugar, to turn brown, and, as we shall see later, as heat has a very important effect on the amount of sugar a liquor can hold in solution, it is clearly important to be able to measure temperature correctly.

MEASURING TEMPERATURE.

The instrument used for measuring temperature is the " thermometer " (from two Greek words, thermos—hot, metron—measure). Thermometers are of many different kinds. Those used for measuring fairly low temperatures almost all work on the property which all common materials, except ice, possess, of expanding or getting bigger when heated. Each material expands a different amount for the same rise of temperature and it is this different amount of expansion that enables the simpler kinds of thermometer to work.

MERCURY-IN-GLASS THERMOMETERS.

The mercury-in-glass thermometer is the most common type of instrument and it works because mercury expands a great deal with heat, whereas glass only expands a very little. The thermometer consists of a very narrow glass tube with a bulb at the bottom. The bulb is filled with mercury and the air is pumped out of the tube above the mercury and the tube is then sealed up. When the thermometer is placed in something hot both glass and mercury get heated up to the temperature of the substance in which the thermometer has been placed. The mercury expands a great deal and the glass a very little. The glass does not expand nearly enough to make room for the hot mercury in the space it previously occupied. The mercury therefore pushes its way up the tube, and the distance it has pushed itself up the tube is a measure of the temperature. Marks are made on the tube to show how far the mercury goes up for various temperatures.

MERCURY-IN-STEEL THERMOMETERS.

Another type of thermometer in common use in the refinery is the mercury-in-steel type. This consists of a steel bulb connected by a very fine steel tube to a pressure gauge. Tube and bulb are filled with mercury. When heated, the mercury expands more than the steel and as the mercury cannot escape it exerts a pressure which can be read off on the pressure gauge whose dial can be marked off in temperature instead of pressure units. This type of thermometer is particularly useful where it is desired to read the thermometer

some distance away from the place where the temperature is being measured.

FAHRENHEIT AND CENTIGRADE.

The first man to standardise a thermometer was a German called Fahrenheit, who arranged the marks on his thermometers so that freezing water showed 32 marks and boiling water showed 212 marks. The Fahrenheit thermometer scale is the one in general use in most English-speaking countries. It was soon realised that the Fahrenheit scale was clumsy and had nothing to recommend it except custom (unlike twelve pence in a shilling or 112 lbs. in a hundredweight, which are very convenient owing to the number of fractions into which they can be split). The Centigrade scale was therefore invented. The Centigrade scale (two Latin words, centum—hundred, gradus—step) is the scale used by T. & L. 0° Centigrade is the temperature of freezing water and 100° Centigrade is the temperature of boiling water.

Centigrade temperatures can be converted into Fahrenheit figures by multiplying by 9 and dividing by 5 and then adding 32. For example, 10° Centigrade multiplied by 9 is 90, divided by 5 is 18, adding 32 is 50° Fahrenheit. Similarly Fahrenheit temperatures can be converted into Centigrade figures by subtracting 32, then dividing by 9 and multiplying by 5. For example, 140° Fahrenheit less 32 is 108, divided by 9 is 12, and multiplied by 5 is 60° Centigrade.

Another way of converting one temperature scale to the other is perhaps easier to remember. It is based on the fact that –40° Centigrade is the same temperature as –40° Fahrenheit. 40 is therefore added to the known temperature ; this figure is multiplied by nine fifths or five ninths as the case may be, and 40 is then deducted. For example, 10° Centigrade plus 40 is 50, multiplied by nine is 450, divided by 5 is 90. Deduct 40 and the answer is 50° Fahrenheit. Again, 140° Fahrenheit plus 40 is 180, multiplied by 5 is 900, divided by 9 is 100. Deduct 40 and the answer is 60° Centigrade.

A table is given in the following pages showing the Centigrade and Fahrenheit equivalents of each degree in each scale from the freezing point to the boiling point and thereafter by larger intervals.

TABLE I.

TEMPERATURE CONVERSION TABLE.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
−17·8	0	−2·2	28	13	55·4	28·3	83
−17·2	1	−2	28·4	13·3	56	28·8	84
−17	1·4	−1·6	29	13·8	57	29	84·2
−16·6	2	−1·1	30	14	57·2	29·4	85
−16·1	3	−1	30·2	14·4	58	30	86
−16	3·2	−0·5	31	15	59	30·5	87
−15·5	4	0	32	15·5	60	31	87·8
−15	5	0·5	33	16	60·8	31·1	88
−14·4	6	1	33·8	16·1	61	31·6	89
−14	6·8	1·1	34	16·6	62	32	89·6
−13·8	7	1·6	35	17	62·6	32·2	90
−13·3	8	2	35·6	17·2	63	32·7	91
−13	8·6	2·2	36	17·7	64	33	91·4
−12·7	9	2·7	37	18	64·4	33·3	92
−12·2	10	3	37·4	18·3	65	33·8	93
−12	10·4	3·3	38	18·9	66	34	93·2
−11·6	11	3·9	39	19	66·2	34·4	94
−11·1	12	4	39·2	19·4	67	35	95
−11	12·2	4·4	40	20	68	35·5	96
−10·5	13	5	41	20·5	69	36	96·8
−10	14	5·5	42	21	69·8	36·1	97
−9·5	15	6	42·8	21·1	70	36·6	98
−9	15·8	6·1	43	21·6	71	37	98·6
−8·8	16	6·6	44	22	71·6	37·2	99
−8·3	17	7	44·6	22·2	72	37·7	100
−8	17·6	7·2	45	22·7	73	38	100·4
−7·7	18	7·7	46	23	73·4	38·3	101
−7·2	19	8	46·4	23·2	74	38·8	102
−7	19·4	8·3	47	23·8	75	39	102·2
−6·6	20	8·8	48	24	75·2	39·4	103
−6·1	21	9	48·2	24·4	76	40	104
−6	21·2	9·4	49	25	77	40·5	105
−5·5	22	10	50	25·5	78	41	105·8
−5	23	10·5	51	26	78·8	41·1	106
−4·4	24	11	51·8	26·1	79	41·6	107
−4	24·8	11·1	52	26·6	80	42	107·6
−3·8	25	11·6	53	27	80·6	42·2	108
−3·3	26	12	53·6	27·2	81	42·7	109
−3	26·6	12·2	54	27·7	82	43	109·4
−2·7	27	12·7	55	28	82·4	43·3	110

Temperature Conversion Table—continued.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
43·8	111	61	141·8	77·7	172	94·4	202
44	111·2	61·1	142	78	172·4	95	203
44·4	112	61·6	143	78·3	173	95·5	204
45	113	62	143·6	78·8	174	96	204·8
45·5	114	62·2	144	79	174·2	96·1	205
46	114·8	62·7	145	79·4	175	96·6	206
46·1	115	63	145·4	80	176	97	206·6
46·6	116	63·3	146	80·5	177	97·2	207
47	116·6	63·8	147	81	177·8	97·7	208
47·2	117	64	147·2	81·1	178	98	208·4
47·7	118	64·4	148	81·6	179	98·3	209
48	118·4	65	149	82	179·6	98·8	210
48·3	119	65·5	150	82·2	180	99	210·2
48·8	120	66	150·8	82·7	181	99·4	211
49	120·2	66·1	151	83	181·4	100	212
49·4	121	66·6	152	83·3	182	104·4	220
50	122	67	152·6	83·8	183	105	221
50·5	123	67·2	153	84	183·2	107·2	225
51	123·8	67·7	154	84·4	184	110	230
51·1	124	68	154·4	85	185	112·8	235
51·6	125	68·3	155	85·5	186	115	239
52	125·6	68·8	156	86	186·8	115·6	240
52·2	126	69	156·2	86·1	187	118·4	245
52·7	127	69·4	157	86·6	188	120	248
53	127·4	70	158	87	188·6	121·1	250
53·3	128	70·5	159	87·2	189	123·9	255
53·8	129	71	159·8	87·7	190	125	257
54	129·2	71·1	160	88	190·4	126·7	260
54·4	130	71·6	161	88·3	191	129·5	265
55	131	72	161·6	88·8	192	130	269
55·5	132	72·2	162	89	192·2	132·2	270
56	132·8	72·7	163	89·4	193	135	275
56·1	133	73	163·4	90	194	137·8	280
56·6	134	73·3	164	90·5	195	140	284
57	134·6	73·8	165	91	195·8	140·6	285
57·2	135	74	165·2	91·1	196	143·4	290
57·7	136	74·4	166	91·6	197	145	293
58	136·4	75	167	92	197·6	146·1	295
58·3	137	75·5	168	92·2	198	148·9	300
58·8	138	76	168·8	92·7	199	150	302
59	138·2	76·1	169	93	199·4	151·7	305
59·4	139	76·6	170	93·3	200	154·5	310
60	140	77	170·6	93·8	201	155	311
60·5	141	77·2	171	94	201·2	157·2	315

Temperature Conversion Table—continued.

Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.	Cent.	Fahr.
160	320	245	473	329·5	625	470	878
162·8	325	246·1	475	330	626	471·1	880
165	329	248·9	480	332·2	630	476·7	890
165·6	330	250	482	335	635	480	896
168·4	335	251·7	485	337·8	640	482	900
170	338	254·5	490	340	644	487·7	910
171·1	340	255	491	340·6	645	490	914
173·9	345	257·2	495	343·4	650	493·3	920
175	347	260	500	345	653	498·9	930
176·7	350	262·8	505	346·1	655	500	932
179·5	355	265	509	348·9	660	538	1000
180	356	265·6	510	350	662	593	1100
182·2	360	268·4	515	351·7	665	600	1112
185	365	270	518	354·5	670	649	1200
187·8	370	271·1	520	355	671	700	1292
190	374	273·9	525	357·2	675	704	1300
190·6	375	275	527	360	680	760	1400
193·4	380	276·7	530	365·6	690	800	1472
195	383	279·5	535	370	698	815	1500
196·1	385	280	536	371	700	871	1600
198·9	390	282·2	540	376·6	710	900	1652
200	392	285	545	380	716	926	1700
201·7	395	287·8	550	382·2	720	982	1800
204·5	400	290	554	387·8	730	1000	1832
205	401	290·6	555	390	734	1037	1900
207·2	405	293·4	560	393·3	740	1093	2000
210	410	295	563	398·9	750	1100	2012
212·8	415	296·1	565	400	752	1148	2100
215	419	298·9	570	404·4	760	1200	2192
215·6	420	300	572	410	770	1203	2200
218·4	425	301·7	575	415·6	780	1260	2300
220	428	304·5	580	420	788	1300	2372
221·1	430	305	581	421·1	790	1316	2400
223·9	435	307·2	585	426	800	1371	2500
225	437	310	590	430	806	1400	2552
226·7	440	312·8	595	432·2	810	1427	2600
229·5	445	315	599	437·8	820	1482	2700
230	446	315·6	600	440	824	1500	2732
232·2	450	318·4	605	443·3	830	1649	3000
235	455	320	608	448·9	840	1927	3500
237·8	460	321·1	610	450	842	2000	3632
240	464	323·9	615	454·4	850	2204	4000
240·6	465	325	617	460	860	2482	4500
243·4	470	326·7	620	465·6	870	2500	4532

PYROMETERS.

For very high temperatures mercury cannot be used as it would boil. High temperature thermometers—usually called "pyrometers" (Greek, pur—fire, metron—measure) are generally electrical. They are usually of one of two types, resistance or thermocouple. Resistance pyrometers consist of a coil of wire protected by a covering. The coil is placed in the vessel, flue or pipe whose temperature is required. An electric current is passed through the coil and the current that is able to pass gets less and less as the coil gets hotter. An electric measuring instrument is put in the electric circuit and the amount of current flowing is measured. This current is a measure of the temperature, and the electric measuring instrument can be graduated in Centigrade degrees instead of in electrical units.

The other type depends upon a curious property possessed by certain metals. If two strips of certain different metals are joined together in perfect contact an electric current is produced if the junction of the two metals is heated. The hotter the metal junction the greater the current. An electric measuring instrument connected to the strips can therefore be made to read the temperature of the metal junction.

MEASURING PRESSURE AND VACUUM.

Measurement of pressure is required on boilers and on all steam-heated plant and on the outlet of pumps. Absence of pressure or vacuum must be measured on vacuum pans, evaporators, and sometimes on the suction side of pumps. Most pressure gauges compare the pressure being measured with the tension of a spring or with the pressure of the atmosphere, or both.

THE BOURDON GAUGE.

The ordinary pressure gauge consists of a flattened tube bent into part of a circle. The tube is closed at one end which is free to move. The other, open, end is attached to the body of the gauge and is connected by a pipe to the vessel whose pressure is to be measured. Any pressure inside the flattened tube will tend to make it get more nearly round, when it will try to straighten itself. The reason for this is that the two sides of the flattened tube are nearly the same length and can form part of a fairly small circle because they are quite close together. But when they are separated by being blown apart by the pressure inside they must form part of a much bigger circle. This action is difficult to explain in words but is just the same as the paper tongue toys which can be blown out a long distance at beano parties. This bent flattened tube is called

a "Bourdon" tube after the Frenchman who invented it. The free closed end of the tube is attached to a pointer by suitable gearing, and as the tube straightens with increased pressure inside it, it operates the pointer through the gearing. A light hairspring on the pointer prevents play in the gearing giving variable readings.

If a Bourdon gauge is constructed with a tube which is quite distinctly oval instead of being flat a lack of pressure or vacuum inside it will allow the atmospheric pressure to press the two sides of the tube nearer together and make it flatter. This will make the tube bend into a smaller circle, and such a gauge can be used for measuring vacuum. The Bourdon gauge is very simple and robust, but is not very accurate and requires frequent checking. It is least reliable on low pressures and when used to measure vacuum
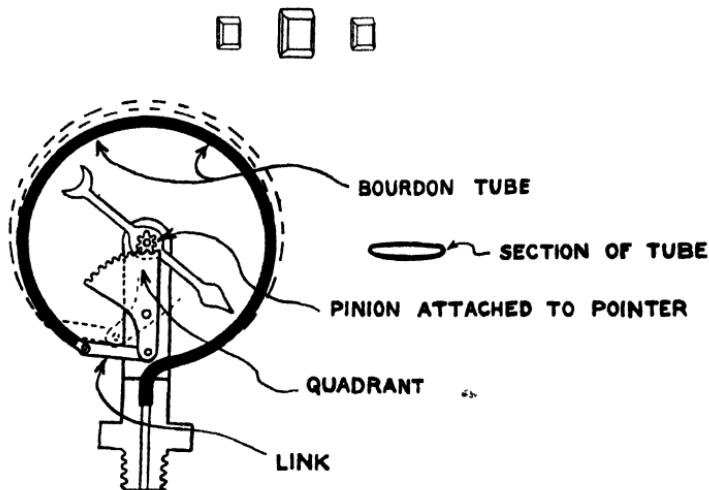
Fig. 7
The Bourdon Gauge.

The Bourdon pressure gauge consists of an oval-sectioned thin tube bent into an almost complete circle. The pressure to be measured is led into the inside of this tube which is closed at its other end. The open end, which is connected by pipe to the vessel whose pressure is to be measured, is fixed into the frame of the gauge. The closed end of the tube is free to move and is attached by means of a link to the short arm of a quadrant. The quadrant is pivoted on the frame of the gauge and its teeth mesh with a pinion on the pointer axle. It will be seen that the tube is almost flat. When pressure acts in the tube it tends to blow the tube from flat into round section. This means that the tube will bend into part of a larger diameter circle. The lengths of the outside diameter

and the inside diameter of the tube cannot change. If the difference between the two diameters changes, as must happen if the tube gets blown out and is thicker, then the tube must try to take up a position where it is part of a bigger diameter circle. If the thickness of the tube increases due to the pressure inside it by 10% then the diameter of the circle into which the tube is bent will increase by 10%. In the diagram shown above, Fig. 7, is a Bourdon tube approximately an inch and a quarter in diameter and ·05 inch thick across the flat. If the pressure is enough to blow out the tube by three-thousandths of an inch, that is a 6% increase in thickness, it causes an increase of 6% in the diameter of the tube's circle. This is shown dotted on the diagram and shows that the quadrant will be so pulled as to make the pointer turn through a complete circle.

THE MERCURY GAUGE.

For accurate vacuum measurement a mercury column is generally used. If a long U-shaped glass tube is half filled with mercury and one end is connected by a pipe to the vessel whose vacuum is to be measured and the other end is left open to the atmosphere the weight of the atmosphere is pressing on one side of the U and the weight of air or steam in the vessel is pressing on the other side. The difference in pressure between the vessel and the atmosphere is shown by the difference in height of the mercury in the two arms. The pressure exerted by the weight of the atmosphere (which is over 100 miles thick and therefore weighs quite a lot) is about 15 lb. per square inch and is sufficient to hold up a column of mercury thirty inches high. This atmospheric pressure varies with the weather. In fine dry weather the atmosphere can hold up a column of mercury nearly thirty-one inches high, while in stormy weather the height of the column held up may be as little as twenty-eight inches. We talk of a vacuum of so many inches. What we mean by this is that the difference of pressure in the vessel and the atmosphere is so many inches of mercury column. A vacuum of, say, twenty-four inches on a fine day is not nearly so good a vacuum as twenty-four inches would be on a stormy day. For accurate work such a mercury gauge must be compared with a barometer. The Bourdon type vacuum gauges, which we use a lot, are dependent on the barometric pressure as the atmosphere is pressing on the outside of the tube.

A mercury gauge can be made to read " absolute " vacuum pressures, that is, the real height of the mercury column it can support without comparing the pressure with that of the atmosphere if the " open " end of the U-tube is sealed up and all the air is removed from the sealed arm.

ABSOLUTE PRESSURE.

The pressures we talk of as so many pounds per square inch are all " gauge " pressures—that is, the pressure read on a gauge whose marks start at 0 at atmospheric pressure. The real or " absolute " pressure is the gauge pressure plus the atmospheric pressure. Vacuum is also spoken of as absolute pressure instead of so many inches of mercury less than atmospheric pressure. A complete vacuum of 29·92 inches has an absolute pressure of 0 lb. per square inch. A vacuum, or pressure of 0 inch, has an absolute pressure of 14·7 lb. per square inch. A gauge pressure of 10 lb. per square inch has an absolute pressure of 24·7 lb. per square inch. Similarly a gauge pressure of 250 lb. per square inch has an absolute pressure of 264·7 lb. per square inch.

THE WATER GAUGE.

For very small pressures such as those produced by fans, pressure is usually measured in " inches of water." Quite a powerful fan giving a pressure of three inches of water only gives a pressure of a little over a tenth of a pound per square inch. The water gauge is a U-tube like the mercury gauge but containing water instead of mercury. As water is much lighter—some thirteen times—than mercury it follows that the water column will be much more sensitive to small pressures than the mercury would be. The suction of a fan or the " draught " it produces is a very slight vacuum and is measured in inches of water. In most cases the actual instrument used consists of some form of sensitive metal gauge of the Bourdon type because a liquid column is not an easy thing to read quickly and accurately. But even if the instrument is not a water gauge, if it is measuring very small pressures it will be marked off in inches of water.

For rough practical purposes 1 lb. per square inch can be considered as being equal to two inches of mercury and twenty-eight inches of water.

Apparatus working by means of hydraulic rams often uses very high pressures, thousands of pounds per square inch. For simplicity these high pressures are generally spoken of, and the gauges made to read in, tons per square inch.

SOLUBILITY.

Sugar is very soluble—that is to say it dissolves very readily—in water. The amount of sugar which will dissolve in water varies with the temperature—the hotter the water the more sugar will dissolve. For example, at 0° C.—the freezing point of water—

TABLE II.

TABLE OF PRESSURE EQUIVALENTS.

Inches of Mercury.	Pounds per Square Inch.	Feet of Water.
1	·491	1·134
2	·982	2·268
3	1·473	3·402
4	1·965	4·536*
5	2·456	5·670
6	2·947	6·804
7	3·438	7·938
8	3·929	9·072
9	4·420	10·206
10	4·912	11·340
11	5·403	12·47
12	5·894	13·61
13	6·385	14·74
14	6·876	15·88
15	7·367	17·01
16	7·86	18·14
17	8·35	19·28
18	8·84	20·41
19	9·33	21·55
20	9·82	22·68
21	10·31	23·81
22	10·81	24·95
23	11·30	26·08
24	11·79	27·22
25	12·28	28·35
26	12·77	29·48
27	13·26	30·62
28	13·75	31·75
29	14·24	32·89
30	14·73	34·02

100 parts of water will dissolve 176 parts of sugar, whereas at 100° C.—the boiling point of water—100 parts of water will dissolve nearly 500 parts of sugar.

SATURATION AND SUPERSATURATION.

When a solution is in such a state that the water has dissolved all the sugar it possibly can, it is said to be in a state of "saturation." If this solution is cooled it must have more sugar in it than it can hold and it is then said to be in a state of "supersaturation." It will also become supersaturated if some of its water is boiled off or evaporated. When a solution is supersaturated it returns to saturation by throwing out crystals or "grain" until it has reached saturation. Some solutions of crystalline substances, such as alum or soda, are quite free-running and thin and throw out their superfluous crystals almost instantaneously, but a sugar solution when it is supersaturated is very sticky and thick, and it throws out its crystals comparatively slowly.

TABLE III.

SOLUBILITY OF SUCROSE IN WATER.

Temperature °C.	Per Cent. Sucrose Dissolved.	Parts of Sucrose in 100 parts Water.	Parts of Water to 100 parts Sucrose.
0	63·7	176	56·9
10	65·2	188	53·2
20	66·8	201	49·7
30	68·5	218	45·9
40	70·4	238	42·0
50	72·5	263	38·0
60	74·5	293	34·1
70	76·8	331	30·4
80	79·2	381	26·2

MEASURING WATER IN A SYRUP OR LIQUOR.

It would appear at first sight that the obvious way to find the amount of water in a syrup would be to boil all the water off a weighed quantity and then to weigh the dry solids left behind. This method, however, takes a very long time and is very difficult to

do correctly. When almost all the water has been boiled off, the syrup becomes very tough and sticky and a high temperature has to be used. This destroys some of the sugar, especially any invert that may be present, and so gives a wrong result. If a weighed amount of sand is mixed in, it is possible with great care to get a correct result, and this sand method is sometimes used, but it is slow and difficult and not suited to everyday use.

THE BRIX HYDROMETER.

The instrument, usually made of glass, called a " hydrometer " (Greek, hudor—water, metron—measure) or Brix spindle gives a very quick, easy and accurate measure of the water in a liquor or syrup. It is based on the " principle of Archimedes," a Greek scientist who, more than 2,000 years ago, discovered the principle in his bath and was so pleased and excited that he rushed out naked, crying " Eureka ! Eureka ! "—" I've got it ! I've got it ! " The principle of Archimedes is that any floating body must displace an amount of liquid exactly equal to its own weight. This means that a floating body will float more deeply in a light liquid than in a heavy one. This is why it is easier to swim in sea water than in fresh water, because the sea water is distinctly heavier than fresh water. If we can measure the depth at which a float is floating in various liquids we can compare the weights of the liquids.

The hydrometer or Brix spindle used in the refinery is simply a glass float weighted at the bottom so that it will float upright, with a narrow stem at the top. The thinner the stem the more sensitive is the instrument. The stem has marks on it which are called Brix degrees.

BEAUMÉ AND BRIX.

The first hydrometer used successfully in industry was Beaumé's hydrometer. This is still used in some sugar works, and there are probably still some men in T. & L. refineries who remember its use. The Beaumé hydrometer was made to measure the weight of common salt liquors, and 15° Beaumé meant that the solution giving such a reading contained 15% of common salt. The Beaumé scale was very clumsy for use with sugar liquors as it meant nothing and tables had to be consulted to give its readings a meaning.

In 1835 a German chemist, Balling, made measurements of the weight of sugar solutions compared with the amount of sugar they contained in order to make hydrometers or spindles which would read directly the amount of sugar in the solution.

Balling left his investigations incomplete. In 1854 an Austrian mathematician called Brix, who, incidentally, lived to the ripe old

age of 92, and who had nothing whatever to do with the sugar industry and who did no experiments at all, took Balling's figures and, by using the mathematical trick called the method of least squares, produced a table from which a series of hydrometers could be made which read directly the percentage of sugar in the liquor by tenths of 1% from 0° to 75° Brix—that is from 0 to 75% of sugar. The Brix spindle is in almost universal use in the sugar industry to-day.

TEMPERATURE CORRECTION FOR BRIX.

When a sugar liquor is heated it expands and, therefore, a given volume weighs less—it is " lighter." If the glass Brix spindle, which also expands when heated, expanded by the same amount, it would not matter. Unfortunately the glass spindle only expands a very little. The result is that a hot liquor gives a lower reading on the spindle than a cooler one We therefore have to make a correction in order to get the true Brix of the sample. Most of our Brix spindles are made to give a correct reading at 20° C. Where a Brix reading has to be taken hot, and this is almost always the case, a table has to be consulted to give us the true Brix at 20° C. This error, due to temperature, is such that for approximately every 11° C. above 20° C. the Brix spindle reads 1° Brix too little.

TABLE IV.

BRIX, TEMPERATURE CORRECTION.

Temperature °C.	Add to Brix Reading.
20	0·00
30	0·80
40	1·65
50	2·54
60	3·46
70	4·50
80	5·80

The above table is only accurate for liquors between 65° and 75° Brix.

BRIX OF VERY HEAVY SYRUPS AND MASSECUITES.

Golden syrup and molasses are so heavy and sticky that the Brix spindle takes too long to settle to its correct floating position and it is very hard to say when it has settled. The spindle also gives a wrong result if grain is present, and we often want to know how much water there is in a massecuite. A measured quantity of water is added to the heavy sample and the Brix then taken. This gives the amount of sugar in the diluted sample, and as the amount of added water is known the Brix of the original can be calculated. This is not as satisfactory a way as might be thought because complications arise when a sample is diluted. We need not go into these complications. For massecuites we must use the dilution method in order to dissolve the grain, but for heavy syrups we have a much better way.

REFRACTION.

When a beam of light passes through one substance into another it is bent out of the straight at the surface between the two substances except when it crosses the surface at right angles. This can be clearly seen if a straight stick is held slanting with part of it in water and part in air. If the stick is looked at obliquely it looks as if it was kinked at the surface of the water. We know that it is not bent, so it must be the light that is reflected from it that is bent. The reason for this bending, or " refraction " (Latin, refractus—broken back) as it is called, is that light travels more slowly through water than through air. Light also travels more slowly through glass than through water. So that a beam of light passing obliquely from air into water gets pulled up lopsidedly and bent at the change of substance.

To get a better idea of the way this bending occurs let us see how other things behave when passing out of one thing into another. Imagine a sandy beach with a dozen bathers about to run down into the sea. Let them stand in a row facing the sea with their arms linked together. If they now run together into the sea they will all enter the water together, and as they cannot run so fast in the water as on the shore they will all slow down together and will keep going straight on, but slower. Now let them stand on the beach with their row facing half right. Still linking arms let them run again into the sea. Those on the left reach the water first and will be slowed down, while those on the right will still be going fast until they enter the water. The line will thus be swung round to the left so that it will be facing more nearly out to sea than the way it started. Exactly the same effect for the same reasons occurs to a beam of light when passing from air into liquid. And the opposite effect occurs when the light passes out of a liquid into air or from glass into a

liquid. Let us see what happens to our bathers when they run out of the sea on to the beach. Let them stand in the sea with linked arms. Let them turn their line half right so that it faces the shore obliquely. Now let them run. Those on the left get out of the water first and are able to run faster, swinging the line round to the right along the beach. Now let them go back into the water and try again, but this time let them face the beach still more obliquely. Let them link arms and run. Those on the left will be out of the water some time before those in the middle and those on the left will speed up, swinging the line round to the right so that they are all running parallel to the shore before those on the right ever got out of the water. Now those on the left will go on running faster than those still in the water on the right, and the line will go on swinging round to the right until the whole line is running back into the water again. In just the same way a very oblique beam of light cannot get out of a " dense " substance into one less dense but is reflected back again. And just as there is clearly a particular angle beyond which our bathers cannot run as a line out of the water so there is a particular angle of obliqueness beyond which no beam of light can get out of one substance into another. This angle depends on the composition of the two substances. This is the basis on which the instrument known as the " refractometer " works.

THE REFRACTOMETER.

The refractometer used by T. & L. was invented by a German called Abbe, who was a partner in and ultimately became sole proprietor of the famous Zeiss glassworks in Jena. Its use for sugar liquors was tried by many chemists before Hugh Main, for many years chief chemist of T. & L.'s Thames refinery, made it a useful instrument by working out and publishing a table for using it on all but the most impure refinery syrups.

Light travels faster through a sugar solution than through glass. The heavier the sugar solution the " denser " it is to light. The Abbe refractometer consists of two similar glass wedges or prisms between which can be placed a film of the syrup to be tested. Light is shone into the lower prism at all sorts of angles. All the light gets bent or refracted more or less in passing into the film of syrup, and the very oblique rays are so much bent that they do not get out of the prism at all, like our bathing party. As the two prisms are identical the light rays that are bent one way in passing out of the first prism into the syrup are bent back an equal amount in passing from the syrup to the second prism. There will be a sudden stop of the light shining out of the second prism where the light that did not get out of the first prism ought to be. The angle of the last light ray that does come out of the second prism is a measure of the angle of the rays that did not get out of the first prism due to the

refraction of the syrup film.   This angle of the last ray out of the second prism can be measured by swinging the eyepiece of the instrument round until the last ray is centred in the eyepiece, that is until the circle seen through the eyepiece is exactly half light and half dark.   The amount by which the eyepiece has been moved to centre the last ray is read off on a scale on the side of the instrument. This scale is divided into divisions of what is known as the refractive index.   Main's table shows the refractive index of all sugar solutions from 0° Brix to 85° Brix.   It makes no difference to the reading if the eyepiece of the instrument is swung round the prisms or if the prisms are rotated with reference to a fixed eyepiece.   The last is the more usual arrangement.   Since Main published his table, numbers of other men have repeated his experiments and for part of the range his tables have been superseded.   The refractometer is graduated for accurate reading at one particular temperature and water at this temperature—usually 20° C.—is circulated round the prisms.

THE REFRACTOMETER.

Light travels at different speeds in different substances, just like other things.   A motor car will go faster on a concrete road than in loose sand.   When light passes from one substance to another it is bent at the surface between the substances except when it passes across at right angles.   In just the same way a motor car, as shown in Fig. 8, below, goes straight on when driven squarely from concrete to sand although the sand will slow it up, but it is being pulled up equally on both sides.

SAND

CONCRETE
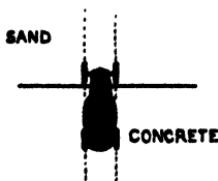
Fig. 8
No Refraction.

Suppose, however, that the motor car leaves the road obliquely, as shown in Fig. 9 below.   As the near side front wheel leaves the road it will cause a drag to the left and the car will start swinging to the left.
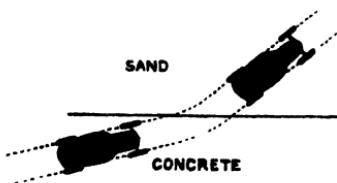
Fig. 9
Refraction.

As soon as the off front wheel gets into the sand the drag will be the same on both sides and the swing will stop only to begin again when the near rear wheel leaves the road and gets into the sand when a further swing to the left will take place until both rear wheels are in the sand. This combined swinging will make the car point more directly into the sand.   When a moving thing, whether motor car or ray of light, moves obliquely from a substance in which it travels fast into a substance in which it travels slower it is swung round or refracted so that it enters the denser substance less obliquely than it left the first substance.

Now consider the case of the motor car leaving the sand and approaching the road obliquely as shown in Fig. 10.
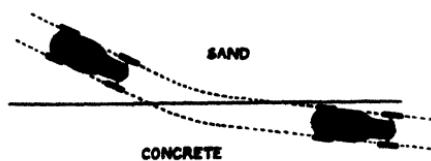
Fig. 10
Refraction.

The off front wheel will come on to the concrete road first and will run more easily so that there will be a drag to the left which will persist until both front wheels are on the road. As soon as the off rear wheel is on the concrete there will again be a drag to the left until both back wheels are on the road. This causes the car to swing to the left in a direction more nearly parallel to the kerb.

SAND

CONCRETE
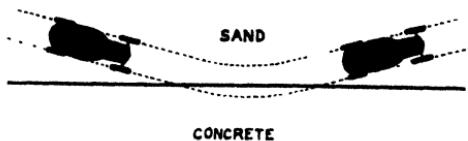
Fig. 11
Reflection.

Now in Fig. 11 we see a very curious state of affairs when the car is driven still more obliquely towards the road. The drag to the left occurs for so long due to the oblique approach that the near side wheels never get on to the concrete at all because the car is swung round so much that it goes back into the sand again. When a moving thing, be it motor car or beam of light, tries to pass very obliquely out of a substance through which it travels slowly there is a certain angle at which it will not get into a substance through which it can travel faster and this angle depends on the relative " densities " of the substances. If a beam of light is passed through one substance at varying oblique angles into another substance any variation in the density of one substance can be measured by measuring the angle at which the light is reflected back, provided the other substance remains constant. This is the principle upon which the refactometer works.

Fig. 12 is a diagram of the refractometer for measuring the Brix of very heavy syrups. The instrument consists of two identical glass prisms between which is squeezed a drop of the syrup to be tested. Light rays from a lamp are directed into the bottom of the lower prism in such a way that they strike the surface of the prism and the surface of the liquid film at various oblique angles. Light travels faster through the liquid than through the glass prism and the lighter the syrup the faster does the light go. This means that in a very heavy syrup only the last few rays will be reflected back into the prism, while more rays will be reflected back if the syrup is lighter. An eyepiece is attached to an arm which is pivoted in line with the centre of the prisms so that it can be swung about until it is in the position shown in the diagram, with the

last refracted ray that comes out of the upper prism central.   This is easily done by swinging round the eyepiece until half the circle seen in the eyepiece is light and half is dark.

In the actual instrument that we use the arrangement differs a little from that shown in the diagram, but these differences do not affect the principle in any way and are only introduced to make the instrument easier to use.
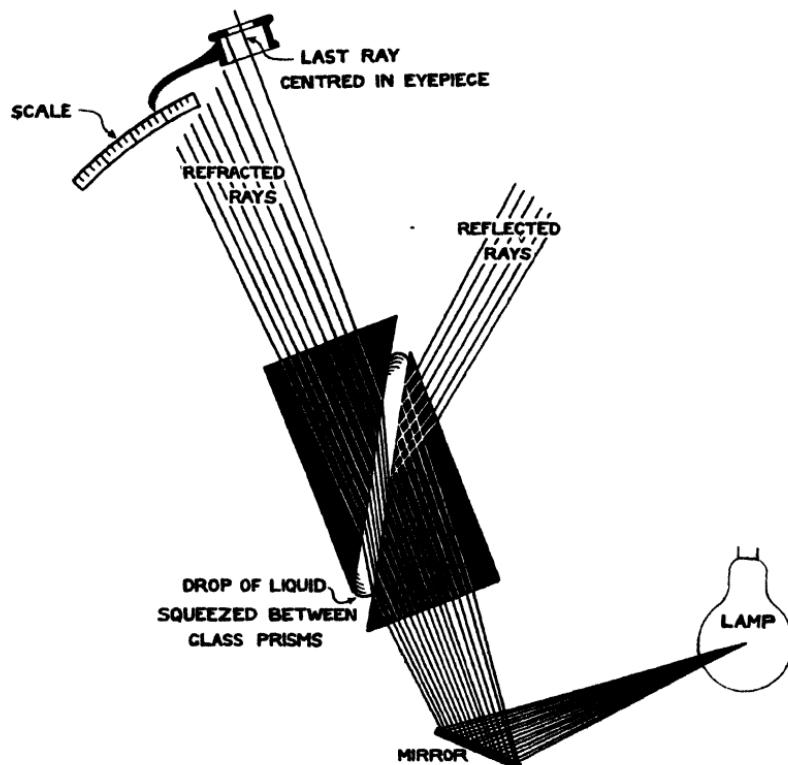
Fig. 12
Diagram of the Principle of the Refractometer.

We use a refractometer on the goldie evaporator at Plaistow in which it is not necessary to centralise the last ray. The refracted rays coming out of the upper prism shine on to a ground-glass screen on which a scale is drawn and a direct reading can be obtained. This instrument is very practical and easily used, but it only has a small range and is not suitable for general laboratory work.

MEASUREMENT OF MOISTURE IN "DRY" SUGARS.

In order to measure the moisture in a dry sugar, for example, to see whether the granulators have been doing their work properly, a weighed amount of sugar is placed in an oven and kept at a temperature of 105° C. This is sufficiently hot to drive off the water but not hot enough to decompose the organic matter. From time to time the sample is weighed. As soon as the weighings show no more loss in weight we know that all the water has been driven off, so that the amount of the loss in weight was the amount of moisture present in the sample. This method can only be used on pure sugars because in impure sugars the moisture is present as a very low syrup or molasses adhering to the crystals and a temperature of 105° C. is not high enough to drive off the water. As the temperature is raised to try to dry the sample so does destruction of organic matter start so that a wrong result is obtained.

CHAPTER 3. CHEMISTRY.

I counted two-and-seventy stenches
All well-defined, and several stinks.

COLERIDGE—Cologne—1828.

Elements and Compounds—Mixtures and Compounds—Solutions—Water—
Oxides—Hydroxides—Alkalis—Acids—Acids, Alkalis and Salts— Neutral-
isation—Carbonatation—Action of Acids and Alkalis on Sugar—pH—The pH
Scale — Impurities — Ash Measurement — Colour — Bacteria and Moulds—
Bacterial Counts—Other Tests.

ELEMENTS AND COMPOUNDS.

Millions of years ago, when the earth was very young, just after
the sun had thrown it off as an incandescent ball of flame, all the
substances which compose it existed as separate elements as they
still do in the sun to-day.   Elements are substances which cannot
be split up into anything simpler.   There are ninety-two of them.
They are divided into two groups, the metals and the non-metals.
As the earth got older and cooler most of the elements combined
together to form compounds.   Some of the original elements still
exist in the free state and are found in the air or in the ground.
For example, the non-metal gas elements, oxygen and nitrogen, are
found uncombined and just mixed together in the air.   Oxygen is
one of the elements that combines most easily with others.   The
reason that oxygen is present in the free state is that it is given
off by plants during their growth.   When sugar is made in a plant
by the combination of CO_2 and water, oxygen is given off.   Some
of the more stubborn metals, such as gold, mercury and tin are
found in the ground in the free uncombined metallic state.   But most
elements do not exist alone but exist on earth as compounds con-
sisting of two, three or more elements combined together in such a
way that they can only be separated by chemical means.   For
example, water, which occupies three-quarters of the earth's surface,
is a compound of the gases hydrogen and oxygen, which are two
non-metal elements   A large part of England consists of chalk or
limestone which is a compound of the metal calcium, the non-metal
carbon and the non-metal gas oxygen.   Although there is more of
the metal calcium in South-east England than any other metal,
hardly any of us have ever seen it because it is so chemically active
that it combines with part of the air or with water or with both as
soon as it is exposed.   It can only be kept in the metallic state if it
is kept in oil or in some other way protected from moisture and air.

MIXTURES AND COMPOUNDS.

It is difficult to see clearly just what the difference is between ordinary mixtures and what are called chemical compounds. It is important to try to understand what this difference is. A mixture can be made in any proportions of the ingredients whereas a chemical compound always has its components in exactly the same proportions under all circumstances. If these proportions change then the compound has changed into a different one.

If we take the two gas elements, hydrogen and oxygen, we can mix them together in any proportions we like and we just have a gas mixture which may have a lot of hydrogen in it or may have a lot of oxygen in it. But if we apply a match to our mixture we get an explosion, and two parts of hydrogen combine with one part of oxygen to form water. Any surplus oxygen or hydrogen from the original mixture is left uncombined. Whatever we do in the way of altering the proportions of the two gases or the temperature or pressure of the gas mixture when we light it we get an explosion, and two parts of hydrogen unite with one part of oxygen to form water. It is quite impossible for us to make water which has a different proportioning of its ingredients. If we managed to get two parts of hydrogen to combine with two parts of oxygen we should not have water but a colourless liquid called peroxide of hydrogen. We could be quite sure that it was not water because if we washed our heads in it we should become platinum blondes !

If we mix the two gases hydrogen and chlorine together we can make gas mixtures of any proportions we like, but if we expose the mixture to sunlight one part of hydrogen will combine with one part of chlorine to form hydrochloric acid. No matter if we had ten parts of hydrogen to one part of chlorine, or one part of hydrogen to ten parts of chlorine in our mixture, when exposed to sunlight, one part of hydrogen would combine with one part of chlorine and the resulting compound will always be hydrochloric acid, which can only consist of one part of each of these gases.

SOLUTIONS.

A solution of a solid in a liquid is a mixture of a more mysterious kind, but it is a mixture and not a compound (complications occur in some solutions where temporary compounds appear to be formed, but these are the concern of the expert chemist and need not trouble us). We can dissolve any amount of sugar we like in water until we reach a point called the saturation point, when no more will dissolve, but by just warming the solution we can make quite a lot more sugar dissolve in the water. By dissolving the sugar in the water we have not changed the chemical structure of either the

sugar or the water nor have we formed a new compound, and we can get our sugar and water back again by boiling off some of the water and condensing the steam which gives us back our water and the sugar will crystallise out. A sugar solution (as far as we are concerned) is just an exceedingly intimate mixture of the two unchanged compounds, sugar and water.

But if we add a little acid to the sugar solution we make the water combine with the sugar to form a different kind of sugar, called invert sugar. Now when water combines with sugar (sucrose) to form invert sugar it makes no difference whatever to the chemical combination how much sugar there was in the sugar solution. When sugar and water combine together to form invert sugar they always do so in the same proportions, and the resulting invert sugar is always the same. Fifty-seven parts of sucrose by weight always combine with three parts of water by weight to form sixty parts by weight of invert sugar. The excess of water, or sugar, as the case may be, is left behind unchanged, together with the acid that we had to add to cause the combination to take place. It should be noted that the acid is not used up at all and is left unchanged. Quite a small amount of acid will cause the inversion of a large amount of sugar and by being left intact at the end of the chemical change proves that invert sugar is not produced by the combination of acid and sucrose, but by the combination of water and sucrose in the presence of acid.

WATER.

Water is the commonest chemical compound and it is by far the most important. Unfortunately it is not quite such a simple compound as might be expected from the fact that it consists simply of one part of oxygen and two parts of hydrogen. As the whole of chemistry depends on the chemistry of water we must try to understand a bit about it.

If we apply a light to a mixture of the gases oxygen and hydrogen an explosion occurs, and one volume of oxygen combines with two volumes of hydrogen to form water vapour and the combination always takes place in these proportions. The reason why the water is produced in the form of vapour is that the explosion, which is an instantaneous chemical combination, gives out so much heat that the resulting water is produced in the form of steam instead of liquid.

All chemical changes take place with a giving up or taking in of heat or other form of energy. As water has been formed with the giving up of a large amount of heat we cannot expect to be able to break water up into its two constituent gases again without putting in a lot of heat or other form of energy. If steam is heated

up to a very high temperature it can be split up into oxygen and hydrogen.   But a great deal of heat at a very high temperature is necessary.   If we pass an electric current through water hardly any heating of the water takes place, but oxygen gas bubbles off at the point where the current enters the water and twice as much hydrogen gas bubbles off at the point where the current leaves it.   It makes no difference to the action or to the proportions of the gases given off what we do to the current as regards volts or amperes.   The whole of the electrical energy disappears without appreciably heating the water, and the two gases which compose water bubble off in the proportions of two to one.   The energy that has been put, by means of the electric current, into the two gases remains in them and is given up again in the form of heat if we mix them together and explode them by means of a match.

OXIDES.

When a substance burns in air it is forming a new chemical compound by combining with oxygen.   The new compounds formed by burning are called oxides.   Whenever oxygen combines with a substance to form an oxide heat is given off.   Sometimes this " oxidisation " is so violent that it takes place almost instantaneously and is called an explosion.   Sometimes it takes place so slowly that the heat given off is not enough to cause our senses to notice it as a burning.   When we ordinarily speak of burning we mean that oxidisation is taking place so fast that the heat given off is enough to make the substances taking part in the reaction red-hot or white-hot.   If we cut a piece of lead with a knife we leave a beautiful shiny surface which in the space of a few hours oxidises until the metal is covered with a grey film of lead oxide which prevents the air getting at the metal underneath and acts as a perfect natural paint.   This oxidisation of lead is so slow that we do not call it burning, but it really is a slow burning.   If we throw very fine lead dust into the air it will oxidise into the same grey oxide, but owing to the fact that a fine dust has much more surface than a solid piece the oxidisation takes place fast enough for the lead dust to take fire.

Many substances can combine with more than one proportion of oxygen to form more than one oxide.   These different oxides of the same substance are often quite different from one another and it could scarcely be believed that they were oxides of the same element and only differed in composition in the proportion of oxygen they contained.

If carbon burns in air the carbon first combines with one part of oxygen to form the oxide of carbon, carbon monoxide, a poisonous gas.   The carbon monoxide will burn and combine with another part of oxygen to form another oxide of carbon, namely, carbon dioxide.   This action can be shown in two chemical equations thus :—

1 part Carbon   + 1 part Oxygen = 1 part Carbon Monoxide
        C   +   O   =   CO

1 part Carbon Monoxide + 1 part Oxygen = 1 part Carbon Dioxide
   CO   +   O   = CO_2
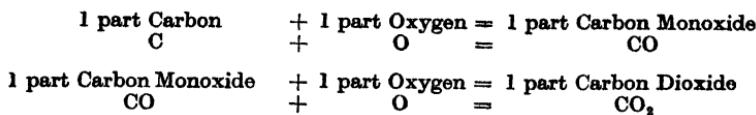
HYDROXIDES.

There is another very important kind of oxide called a hydroxide, in which hydrogen and oxygen are joined together in equal parts to form what is called a hydroxide or hydroxyl group (OH). These hydroxyl groups will often combine with elements in just the same way as oxygen alone will. When an element combines with hydroxyl the resulting compound is called a hydroxide. These (OH) or hydroxyl groups cannot exist alone but must be combined with other elements.

Now water consists of two parts of hydrogen and one part of oxygen and its chemical formula is generally written H_2O, that is to say it is a simple oxide of hydrogen. But the way it behaves when combining with other substances, both elements and compounds, shows that it is really a hydroxide of hydrogen, that is to say that it consists of hydrogen and a hydroxyl group and its formula should therefore be written H(OH).

If water consists of hydrogen and hydroxyl groups it may well be asked why it should be split up by an electric current into oxygen and hydrogen, instead of into hydrogen and mysterious hydroxyl. The answer is that hydroxyl cannot exist by itself. The electric current does split the water into hydrogen and hydroxyl groups, but the hydroxyl groups immediately combine together to form oxygen and water :—

2 parts Water + Electric Current = 2 parts Hydrogen + 2 parts Hydroxyl
    2H(OH)   =   2H   +   2(OH)

    2 parts Hydroxyl =   1 part Water   + 1 part Oxygen
    (OH) + (OH) =   H(OH)   +   O
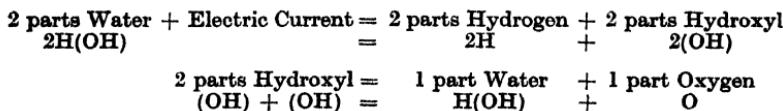
ALKALIS.

The two constituents of water, hydrogen and hydroxyl, are capable of combining with other substances to form the two most important kinds of chemical compound, namely, acids and alkalis.

If any of the light active metals, such as potassium or sodium or calcium are dropped into water they displace the hydrogen part of the water and combine with the hydroxyl part to form hydroxides, and hydroxides are what are called alkalis. These light metals are so eager to combine with the water and the combination is so violent that the heat given off is sufficient to melt the metal, and, in the case of potassium, to light the gas hydrogen as it is given off. The

action in the case of potassium, whose chemical symbol is K, is as follows :—

Water	+	Metal	=	Caustic Potash	+	Hydrogen
(Hydrogen Hydroxide)		(Potassium)		(Potassium Hydroxide)		
H(OH)	+	K	=	K(OH)	+	H
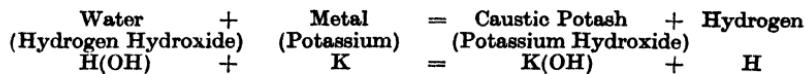
These hydroxides, which are formed by the combination of the light metals with the hydroxyl part of water are all strong alkalis. Alkalis are chemically the opposite of acids and are rather difficult to define. They are corrosive compounds. They are soluble in water. They neutralise acids to form compounds that are called salts. They turn certain coloured substances a particular colour which is different from the colour which the substance turns in the presence of acid.

ACIDS.

A number of the non-metal elements or their oxides will combine with the hydrogen part of water, replacing the hydroxyl part. These compounds are called acids. The freed hydroxyl often gives up its spare oxygen to combine with the non-metal oxide to form that part of the acid which is called the acid radicle. For example, when the non-metal carbon burns to carbon dioxide this gas will combine with water to form Carbonic Acid. The carbon dioxide replaces the hydroxyl in the water and the oxygen liberated by the self-combination of the hydroxyl combines with the carbon dioxide to form the carbonic radicle of the acid. We can write the changes out in a sort of diagram shown in Fig. 13.

Acids have the property of turning certain substances, called " indicators," a particular colour and alkalis turn these substances another colour. The dye, litmus, is turned pink by acids and blue by alkalis.

ACIDS, ALKALIS AND SALTS.

Acids and alkalis have very strong opposite properties and when brought into contact with one another neutralise each other to form new compounds, which are called salts. Acids are sour gases or liquids which contain hydrogen. This hydrogen can often be replaced by metals which combine with the non-hydrogen part of the acid, the part called the acid radicle, to form salts which are generally neutral, that is to say they have neither acid nor alkaline properties.

If a piece of iron is dropped into sulphuric acid the iron appears to dissolve in the acid and hydrogen gas comes off in bubbles. Actually the iron does not really dissolve. It combines with the sulphuric or sulphate part of the acid and replaces the hydrogen and
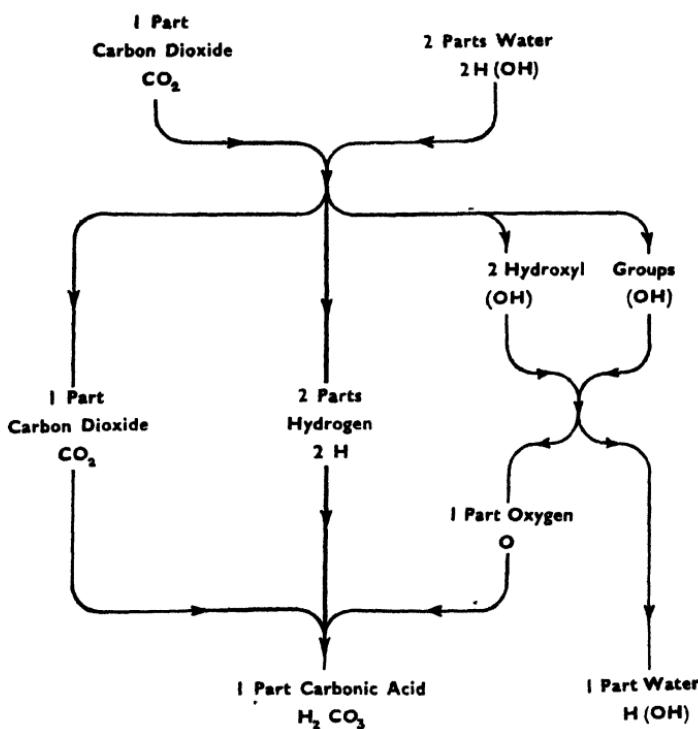
Fig. 13
Formation of an Acid.

forms the salt called green vitriol or iron sulphate. Iron sulphate is soluble in water so that immediately the salt is formed it dissolves, and being green in colour the liquid gradually turns green as the iron disappears. When the iron has all combined the hydrogen no longer bubbles off. If the piece of iron was large it may use up all the acid before it disappears, in which case the hydrogen will also stop bubbling. We can write the action out thus (Fe is the chemical symbol for iron) :—

Iron	+	Sulphuric Acid	=	Green Vitriol	+	Hydrogen
		(Hydrogen Sulphate)		(Iron Sulphate)		
Fe	+	H_2SO_4	=	$FeSO_4$	+	2H
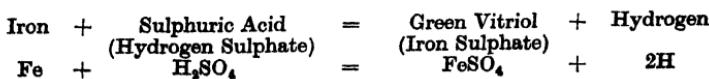
When acids and alkalis neutralise each other to form salts, water is formed as well. There are hundreds of different kinds of salts, many of which can be obtained by the action of acids upon metals as in the case of iron just described.

If we add sulphuric acid to caustic potash the two compounds neutralise each other and the salt potassium sulphate and water are formed :—

1 part		2 parts		1 part		2 parts
Sulphuric Acid	+	Caustic Potash	=	Potassium Sulphate	+	Water
H_2SO_4	+	$2K(OH)$	=	K_2SO_4	+	$2H(OH)$
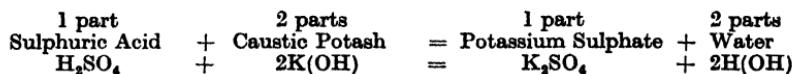
A very interesting complete circle of chemical change of water forming acid and alkali when combining with a metal which has been liberated from a salt, and the recombining of the acid and the alkali to form water and the original salt can be shown in the case of common table salt, sodium chloride. If an electric current is passed through melted common salt, the salt is split up into its two component elements, chlorine gas and the metal sodium. If the sodium is added to water it will displace the hydrogen and combine with the hydroxyl to form the strong alkali caustic soda. If we collect the hydrogen gas which comes off the water when the sodium is replacing it and mix it with the chlorine gas which came off the melted salt under the influence of the electric current, and expose the gas mixture to sunlight, the two gases will combine together with almost explosive violence to form hydrochloric acid. So that from water and a salt we have formed an acid and an alkali and there is nothing left over. If we now add the acid to the alkali, that is, mix the hydrochloric acid and the caustic soda, they will neutralise each other to form water and sodium chloride, the common salt that we started with. So that we are back where we started. By means of the electric current we split the salt up into its components, the metal and the acid radicle. The metal then combined with water and replaced the hydrogen to form an alkaline hydroxide and the hydrogen which it displaced combined with the acid radicle from the salt to form an acid. Finally the acid and the alkali neutralised each other to form the original salt and water with which we started. The cycle of reactions are shown diagrammatically in Fig. 14.

It will be seen that in this chain of reactions heat energy is given up on three occasions, whereas energy has only been put in once. The amount of electrical energy that must be used to split up the salt will be exactly equal to the three amounts of heat which are given off added together.

NEUTRALISATION.

Although, generally speaking, the salts that are produced by the action of acids and alkalis upon one another are neutral, that is to say they have neither acid nor alkaline properties, some salts are in fact acid and some act definitely as alkalis. Even salts that are entirely neutral can neutralise acids provided that the acid radicle in the salt is weaker or less stable than the acid. How this

SALT
Sodium Chloride
Na Cl

Electric Energy
Put In

WATER
Hydrogen
Hydroxide
H (OH)

METAL
Sodium
Na

Heat Energy
Given Out

ACID RADICLE
Chlorine
Cl

HYDROGEN
H

ALKALI
Sodium
Hydroxide
Na (OH)

Heat Energy
Given Out

ACID
Hydrochloric Acid
H Cl

Heat Energy
Given Out

WATER
Hydrogen Hydroxide
H(OH)

SALT
Sodium Chloride
Na Cl
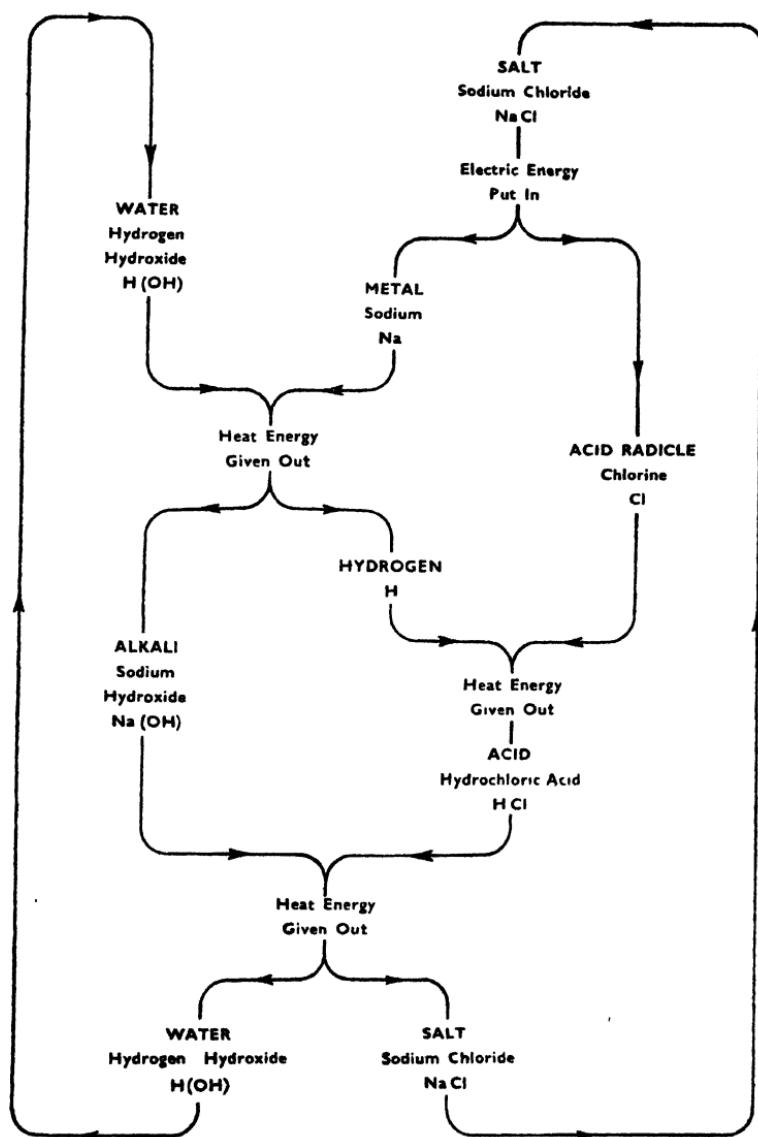
Fig. 14
Cycle of Chemical Reactions.

neutralisation action by a neutral salt is possible we shall see shortly. But only strong acids can be neutralised by neutral or weakly alkaline salts. For the neutralisation of weak acids we must use a strong alkali, and that is why we use lime to remove the slight trace of acid in the raw melter.

The commonest alkaline salt is soda, or sodium carbonate, and we use it for neutralising acidity in various parts of our process. For example, the Thames refined syrups are inverted with hydrochloric acid. This acid makes the sucrose combine with water to form invert sugar. When sufficient invert sugar has been formed it is necessary to stop the inversion by neutralising the acid. For this purpose soda is used. The metal sodium leaves its carbonate radicle and combines with the chlorine radicle of the acid to form sodium chloride or common salt. The hydrogen of the acid combines with the carbonate radicle to form carbon dioxide and water. It may be wondered why carbonic acid is not formed. The reason is that carbonic acid is broken up by quite a low temperature into water and carbon dioxide so that it cannot remain in a hot solution. We can write this neutralisation out thus :—

2 parts		1 part		2 parts		1 part		1 part
Hydrochloric	+	Sodium	=	Sodium	+	Water	+	Carbon
Acid		Carbonate		Chloride				Dioxide
$2HCl$	+	Na_2CO_3 =		$2NaCl$	+	$H(OH)$	+	CO_2
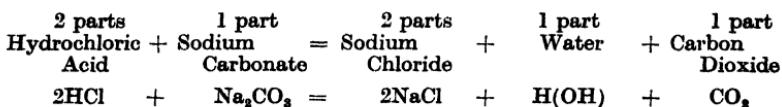
It will be noticed that the salt resulting from this neutralisation is common salt which dissolves easily in water or liquor, so that at the end of inversion with hydrochloric acid and neutralisation with soda we leave a little salt in the solution, which gives the syrup a slight salty taste.

In the case of the Goldie inversion at Plaistow we do not want to leave anything in the syrup which might give it a salt taste, so we must use an acid and an alkali which will give, on neutralising, a salt which will not dissolve in water but will be thrown out as a cloud or precipitate which can be filtered out. We use sulphuric acid and neutralise it with chalk. Chalk or calcium carbonate is a completely neutral salt and it will not neutralise weak acids, but it will neutralise a strong acid like sulphuric acid because the strong acid radicle displaces the weak carbonate radicle and joins up with the metal to form the salt calcium sulphate which does not dissolve in water. The hydrogen released from the sulphuric acid combines with the carbonate radicle to form water and carbon dioxide.

| (Sulphuric Acid)		(Chalk)						
Hydrogen	+	Calcium	=	Calcium	+	Water	+	Carbon
Sulphate		Carbonate		Sulphate				Dioxide
H_2SO_4	+	$CaCO_3$ =		$CaSO_4$	+	$H(OH)$	+	CO_2
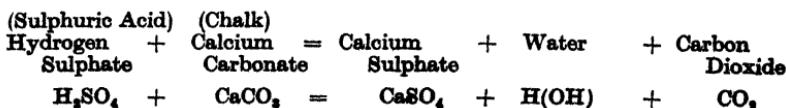
The calcium sulphate is thrown out as a cloud and is removed by filtering. The carbon dioxide bubbles off. So that we have added an acid to cause the inversion of the sucrose and have stopped the inversion by neutralising the acid with a neutral salt and have left nothing behind in the syrup except a little water.

CARBONATATION.

Carbonatation is a process for filtering sugar liquors which will be discussed later in the book. Only its chemistry will be considered now and this only because it will help with the understanding of simple chemistry.

The metal calcium is like the metals potassium and sodium, namely, it combines at ordinary temperatures with the oxygen of the air. If the metal calcium is exposed to the air it will combine with oxygen to form calcium oxide or quicklime.

(Metal) (Quicklime)
Calcium + Oxygen = Calcium Oxide
Ca + O = CaO
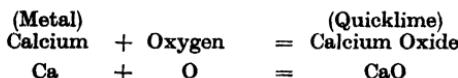
In practical manufacture it is much cheaper to obtain quicklime from chalk or limestone by heating to a fairly high temperature, when the carbonate radicle is broken down and carbon dioxide is given off leaving quicklime behind.

(Chalk) (Quicklime)
Calcium Carbonate + Heat = Calcium Oxide + Carbon Dioxide
$CaCO_3$ = CaO + CO_2
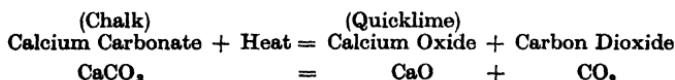
This oxide, quicklime, combines very readily with water to form calcium hydroxide or slacklime.

(Quicklime) (Slacklime)
Calcium Oxide + Water = Calcium Hydroxide
CaO + $H(OH)$ = $Ca(OH)_2$
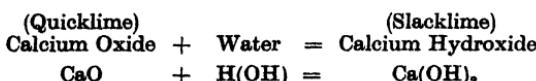
Calcium hydroxide is a strong alkali and combines very readily with carbonic acid. Carbonic acid is always ready to form from the carbon dioxide of the air and the moisture in the air. If slacklime is left exposed to ordinary air it gradually neutralises itself with carbonic acid to form chalk or calcium carbonate.

(Carbonic Acid) (Slacklime) (Chalk) (Water)
Hydrogen + Calcium = Calcium + Hydrogen
Carbonate Hydroxide Carbonate Hydroxide
H_2CO_3 + $Ca(OH)_2$ = $CaCO_3$ + $2H(OH)$
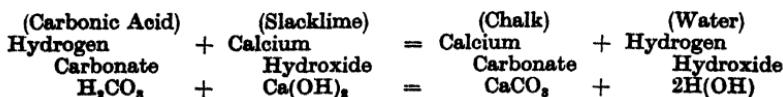
To get good filtration of a sugar solution we want to entangle the gummy slimy matters in a sort of chemical felt or blanket so that the filter cloth will not get slimed up, and it has been found

that freshly precipitated chalk is excellent for the purpose. We therefore take quicklime and slake it to slacklime with water. This, as has just been explained, turns it into calcium hydroxide which is a strong alkali. We add this to our brown liquor in the form of a cream. When it is in the liquor it dissolves because although calcium hydroxide does not dissolve very readily in water there is such a lot of liquor and comparatively little lime that the liquor can readily dissolve it. Carbon dioxide gas is then bubbled through the liquor. We get this carbon dioxide by washing the dust and sulphur out of our boiler flue gases. (The burning of coal into carbon dioxide and water is described in Chapter 6.) The carbon dioxide in bubbling through the liquor combines with the water to form carbonic acid and immediately combines with and neutralises the lime that is dissolved in the liquor. The chalk thus produced comes out of solution in a cloud carrying with it most of the gummy slimy matters and many of the organic colouring matters. The reason why the carbon dioxide can combine with the water in the hot liquor to form the unstable carbonic acid is that there is something, namely, the lime, greedily awaiting it and ready to combine instantly with it. So that while carbonic acid cannot exist in the hot liquor as an acid it can form for a minute instant in order to combine with the alkali to form the stable carbonate of calcium—chalk.

The reason that we buy quicklime and slake it ourselves instead of buying slacklime is that 4 tons of quicklime produce 5 tons slacklime, so that we save the railway freight on 1 ton in 5 by buying quicklime.

It is impossible to go more deeply into chemistry in this book. It is hoped that the foregoing paragraphs have given some sort of idea of the nature of chemical combination and of the splitting up and combining of chemical compounds, and some idea as to the more important types of chemically active bodies.

ACTION OF ACIDS AND ALKALIS ON SUGAR.

All acids cause sucrose in a syrup or liquor to turn into invert sugar. The more powerful the acid or the greater the amount of acid present the faster is the inversion. Alkalis do not cause inversion but they cause a destruction of sugars, particularly of invert sugar. It is clearly desirable to keep sugar liquors as near neutral as possible. If this is an unattainable perfection we like to err on the side of alkalinity as a little destruction of invert is not so damaging to our product as the making of invert.

Newly burnt char is alkaline but after a char cistern has run for a time it becomes acid and causes inversion unless the liquor is put on slightly alkaline to counteract the acidity. Golden syrup contains a lot of invert and is therefore kept acid in order to be quite

safe from the invert destruction which would take place if the syrup were allowed to become alkaline.

Clearly it is very important that there should be an easy and reliable way of measuring acidity and alkalinity.

pH.

The measure of the acidity or alkalinity of a liquid is what is known as its pH number.

We have seen that water consists of Hydrogen, or acid-making material, and Hydroxyl, or alkali-producing material, combined together in equal quantities. In water or water solutions some of this Hydrogen and Hydroxyl is in the uncombined or " dissociated " state. If the amounts of this free or dissociated Hydrogen and Hydroxyl are equal then the solution is called neutral—that is to say, the Hydrogen ions, as the free particles are called, are exactly equal in number to the Hydroxyl ions.

It has been found possible to measure the quantity of this free Hydrogen and free Hydroxyl in pure water and the amount has been found to be 1 gram in 10 million litres of water. This quantity is the same as 1 lb. in 1,000 million gallons. The fraction used in practice is the 1 gram in 10 million litres or expressed as a fraction :—

$$\frac{1}{10,000,000} \text{ of H and } \frac{1}{10,000,000} \text{ of OH.}$$

If acid is added to the water this increases the quantity of free Hydrogen particles or ions. If sufficient is added to increase the amount by ten times, then the amount of free OH ions is reduced to one-tenth of the previous amount or concentration. The fractions then become : $\frac{1}{1,000,000}$ of H and $\frac{1}{100,000,000}$ of OH.

Now these fractions are clearly the measure of the acidity or alkalinity of the solutions, but they are too cumbersome for practical use. A simple figure which tells us all we want to know is the number of noughts in the denominator of the fraction. This number of noughts is called the " p " number. So that " pH " means the number of noughts in the denominator of the fraction which represents the amount of free Hydrogen particles or ions in a solution. Similarly " pOH " means the number of noughts in the denominator of the fraction representing the amount of free Hydroxyl ions. The pure water fractions were :

$$\frac{1}{10,000,000} \text{ of H and } \frac{1}{10,000,000} \text{ of OH.}$$

There are seven noughts in the denominators of these fractions. So that the pH and the pOH of pure water are 7. Therefore pH 7 means exact neutrality. In the example given earlier when acid was added to increase the acidity tenfold there were only 6 noughts in the fraction so that the pH was 6. The pOH number could be taken. This goes in exactly the opposite way to the pH. At neutrality the numbers are pH 7 and pOH 7. When ten times the amount of free H ions are added the numbers are pH 6 and pOH 8. In practice the pOH numbers are never used ; the pH numbers are those always employed.

The table on the next page shows the various conditions quite clearly.

It will be seen that each pH number signifies ten times the state of the preceding one. pH 5 is ten times as acid as pH 6, and pH 9 is ten times as alkaline as pH 8.

Having now got a simple scale such as the " p " (or number of noughts in the denominator) gives us, there is no reason why we should not use decimals to indicate an acidity between two pH numbers. An acidity intermediate between pH 6 and pH 7 can be written as pH 6·5 although it is impossible to have a fraction with $6\frac{1}{2}$ noughts in the denominator. The real fraction representing pH 6·5 would be far too clumsy for practical use, whereas decimals in the pH scale are neat and simple.

The neutral point of pure water varies with the temperature. The pH scale is based on conditions at a temperature of 22° C.

pH can be measured in two ways. Either by an electrical method too complicated to explain here, or by using what are called indicators. An indicator is a substance which changes colour when the liquid it is mixed with is at a particular pH. A mixture of these indicators has been devised which, when added to a liquid whose pH is required, will turn a definite colour for a particular pH. This mixture is called the " universal indicator " and its range of colours is like that of the rainbow. pH 4 is red, pH 7 is yellow-green and pH 10 is violet. When the approximate pH has been found by means of the universal indicator its exact value can be found by using indicators which change colour on either side of the value given by the universal indicator.

The extreme ends of the pH scale are never found in any solution. The strongest acidity met with is pH 0·5 which is the pH of strong hydrochloric acid. The strongest alkalinity found is about pH 13·5 which is the pH of concentrated caustic soda solution.

The pH scale was invented by a Swede called Sørensen in 1909.

Some of the brown colour in sugar liquors is indicator colour,

TABLE V.

THE pH SCALE.

State of Solution.	Fraction representing the concentration of Hydrogen ions or Acid-producing particles.	Number of Noughts in Denominator " pH."	Fraction representing the concentration of Hydroxyl ions or Alkali-producing particles.	Number of Noughts in Denominator " pOH "
Maximum Acidity	$\frac{1}{1}$	0	$\frac{1}{100,000,000,000,000}$	14
Strongly Acid	$\frac{1}{10}$	1	$\frac{1}{10,000,000,000,000}$	13
	$\frac{1}{100}$	2	$\frac{1}{1,000,000,000,000}$	12
Moderately Acid	$\frac{1}{1,000}$	3	$\frac{1}{100,000,000,000}$	11
	$\frac{1}{10,000}$	4	$\frac{1}{10,000,000,000}$	10
Slightly Acid	$\frac{1}{100,000}$	5	$\frac{1}{1,000,000,000}$	9
Faintly Acid	$\frac{1}{1,000,000}$	6	$\frac{1}{100,000,000}$	8
NEUTRAL	$\frac{1}{10,000,000}$	7	$\frac{1}{10,000,000}$	7
Faintly Alkaline	$\frac{1}{100,000,000}$	8	$\frac{1}{1,000,000}$	6
Slightly Alkaline	$\frac{1}{1,000,000,000}$	9	$\frac{1}{100,000}$	5
Moderately Alkaline	$\frac{1}{10,000,000,000}$	10	$\frac{1}{10,000}$	4
	$\frac{1}{100,000,000,000}$	11	$\frac{1}{1,000}$	3
Strongly Alkaline	$\frac{1}{1,000,000,000,000}$	12	$\frac{1}{100}$	2
	$\frac{1}{10,000,000,000,000}$	13	$\frac{1}{10}$	1
Maximum Alkalinity	$\frac{1}{100,000,000,000,000}$	14	$\frac{1}{1}$	0

that is to say if the liquor is alkaline the colour is dark, whereas if it is acid the colour is much lighter. It is therefore important when comparing colours that they should be taken at the same pH, or at any rate that the pH should be taken into account.

The impurities in a sugar or sugar liquor consist of a large number of different compounds present in very small quantities. It is an almost impossible task to find out the exact quantity and identity of all these different impurities, and it would be utterly impractical to try to do so for the purpose of process control. Such an analysis would take days or weeks and would then not be at all reliable, whereas we want a reliable figure in a few minutes. So we divide the impurities into two groups which we term " ash " and " organic." The " ash " we can measure quickly and consistently.

The ash is a measure of the mineral impurities, that is to say of the metallic salts and metallic oxides. The organic is a measure of the vegetable impurities, gums, colouring matters, etc.

An " organic " substance is a compound which contains carbon and which exists in or is derived from a live substance or something which has at some time been alive. For example, sugar is an organic compound.

Many of the metals are combined with organic radicles in the form of organic salts, so that the mineral matters are in some part inextricably linked with the vegetable matters. We try to measure the mineral matters as salts whether organic or inorganic, and the substances which we term organic impurities are those which contain no metallic elements.

All organic substances are able to be burnt or split up by means of heat and some of them are partly burnt or broken up at quite low temperatures. So that if we heat up a sample of sugar we can burn off the sugar and all the other organic substances and leave behind the " ash," which consists of metal oxides or very heat-resisting salts. Now many of the metals existed in the sugar sample as organic salts and by heating them most of the organic radicle will be burnt off, leaving oxides or carbonates of the metals as the ash. This ash will clearly not be a true measure of the metal salts, the quantity would be too small. In order to measure the salts as salts we convert them all to sulphates and measure the resulting " sulphate ash." Sulphates are very stable salts and are not split up by moderately high temperatures. But even this does not give us a true result because sulphates are heavy salts, heavier than most of the organic salts which were present It has been found that nine-tenths of the weight of the sulphate ash is a fairly close approx-

imation to the real true mineral matter, and this figure of nine-tenths of the sulphate ash is used by the sugar chemists of the world as a measure of the metal salts or mineral impurities in a sugar sample.

By methods which will be described in the next chapter the amount of sucrose and invert sugar can be measured. The amount of water can be found by one of the methods described in the previous chapter. The sulphate ash is measured and nine-tenths of its value is taken as the measure of the ash. What is left unac-. counted for is the organic impurity.

This method of measuring the ash by " cooking " the sulphate ash figure and measuring the organic impurities by calling every-thing unaccounted for " organic " is not, of course, scientifically accurate. But it is the only practical way out of a very complicated chemical problem, and it gives consistent results that are useful for comparison and record provided that the same method is always used.

ASH MEASUREMENT.

In order to measure the metallic impurities which we call " ash " a weighed amount of the sugar or syrup is placed in a platinum dish and a few drops of strong sulphuric acid are added. , The sample is heated cautiously until the sugar melts, swells up and blackens. A few more drops of sulphuric acid are then added which helps to break up the tough black mass and converts all the salts into sulphates, which are very stable salts and do not break up under moderate heat. The dish is then heated to dull redness when all the sugar and other organic matter is burnt off. The remaining " ash " is then weighed. This ash consists of sulphates of all the metals which were present. We deduct one-tenth from the weight obtained and call this the weight of the ash.

Except when we want to get a complete analysis of a sample we cannot measure the organic. In most of our refining processes the organic follows the ash, and ash measurement gives us the guidance that we require. But wherever sugar destruction is to be watched for it is necessary to measure the organic. When we find that the proportion of organic to ash impurities has risen we must suspect that the increase of organic has been brought about by a destruction of sugar.

The method of measuring the ash by burning off the organic substances to get the remaining ash is slow, and we often require to know the ash almost from minute to minute. We have an electrical method which only takes a minute or two and which is quite accurate enough for ordinary process control. The more ash there is in a syrup or liquor the more readily will the liquid pass an electric current. A battery is connected to two metal rods which

dip into the sample to be tested and the amount of current that passes is measured. The ash can then be read off a table. This table has been prepared by comparing the " electric ash " for various samples with the real ash obtained by burning.

COLOUR.

As one of the principal tasks of the sugar refiner is the removal of colour, it is essential that we should be able to put a figure on colour for the purposes of comparison and record. Many elaborate colour-measuring instruments have been invented and tried, but none of them are so generally satisfactory as the rather crude instrument which we used for many years. This is called the Lovibond " tintometer," invented by Lovibond for measuring the colour of beer. An instrument made for such a noble purpose surely merits our attention ! It consists of a box with an eyepiece at one end and a window at the other. The space between eyepiece and window is divided lengthways into two parts from eyepiece to window. One of these parts contains the " cell," a narrow metal box with glass ends. The other part is provided with grooves to receive the tinted glasses with whose colour the colour of the liquid is compared. The cell is filled with the liquor sample always made up to a standard Brix. It may also be necessary to adjust its pH by the addition of a little acid or alkali because, as has already been explained, some of the sugar colour may be " indicator " colour. A white light is shone into the window of the instrument and tinted glasses are dropped into the grooves until the colour of the liquor is exactly matched by the colour of the glasses. The glasses are numbered, the darker the tint the higher the number, so that we can say the colour is such and such a figure. For very dark syrups a very short cell is used and for lighter-coloured syrups a longer cell is used. For example, we measure the colour of brown liquor in a one-inch cell, fine liquor in a six-inch cell and white sugars are made into a solution and their colour measured in a thirty-two-inch cell.

Nowadays we are using a rather more elaborate version of the Lovibond tintometer in which an arrangement of prisms brings the view of the sample and the tint glasses so close together that there is no visible line between them. In this instrument also the tint glasses are mounted on a frame so that any glass can be instantly put into position without the need to slide the glasses in or out of grooves. This instrument is called the Rosenhain-Shuster Colorimeter.

BACTERIA AND MOULDS.

Bacteria are the smallest and simplest known forms of life. They are tiny things quite invisible separately to the naked eye. The largest is barely one-thousandth of an inch long. ⁺The smallest are invisible to the most powerful microscope and cannot be trapped

on the finest filter. The smallest that can be seen under the microscope is about one eighty-thousandth of an inch long. Their structure is so simple that it is difficult to say whether they should be called animal or vegetable. The moulds are a little more complicated in structure and show some of the definite characteristics of vegetables.

Both bacteria and moulds can breed unbelievably fast. Many common bacteria double their number every hour, while in milk under some conditions a new generation occurs every twenty minutes. If bacteria are doubling their number every hour it means that each one will produce 32 descendants in six hours, 2,000 in twelve hours and 8,000,000 in twenty-four hours. Bacteria exist in the air and every thing and every particle of dust carries a number.

There are hundreds of different kinds of bacteria. Those that trouble us in the refinery are generally quite different from those that make us ill. All bacteria are not harmful. Plants would not grow properly if there were not bacteria at work in the soil. We depend for the proper digestion of our food on bacteria which live in our intestines. The bacteria which trouble us in the refinery are those that live on and destroy sugar. They breed with great vigour in dilute warm solutions. Bag water and char lights are favourite homes for them and they are sometimes present in such numbers as to make the liquid look cloudy. They feed on the sugar, breaking it up into various other substances. Each bacterium or mould produces a characteristic substance from the sugar it destroys. Some bacteria produce acetic acid, easily recognised by the smell of vinegar. Some produce butyric acid which gives the foul smell which is generally present when sugar has decomposed in a dirty corner, for example, under a loose floor tile. Yeast produces alcohol which is easily recognised by its smell.

In addition to the direct damage done by bacteria in destroying sugar most bacteria produce acids which cause harmful inversion. The change brought about by bacteria and moulds in breaking up the sugars into other substances is called " fermentation " and is frequently accompanied by frothing owing to the gas carbon dioxide being liberated as the sugar is destroyed. (In Chapter 1. we stated that sugar was made by the plants from carbon dioxide and water.)

Great enemies of the beet sugar factory and the refiner are the " Leuconostoc " bacteria. Leuconostoc bacteria are usually present in raw beet sugars and they only breed in alkaline solutions. They can breed and do damage extraordinarily rapidly. They turn the sugar into a sticky compound called dextran. In years past when we have been working low continental beet sugars char cisterns being washed off have become completely choked with the ropey, jelly-like mass of dextran and leuconostoc. Yeast is a mould which is very dangerous, because its destructive action is so ex-

ceedingly rapid, although it has only troubled us on very rare occasions.

If bacteria and moulds were left unchecked they could destroy thousands of tons of sugar in a few days. In fact if we did not keep them in check our refineries would be quite unworkable. Fortunately they do not breed in heavy liquors, most of them are destroyed by heat and most of the sugar-eating bacteria and moulds are big enough to be removed by filtration.

One type of bacteria is very difficult to deal with. These are the group called " thermophils " (Greek, thermos—hot, philos—loving) which are not killed by ordinary process temperatures. Thermophils are great enemies of the canners as they are not killed in the cooking and may develop weeks after the can has left the canner and spoil the canned food. Thermophils are present on almost all particles of dust. The reason for building the pan house at Plaistow with no opening windows was to keep out the thermophils which are supposed to be washed out of the incoming air in the air-conditioning plant.

BACTERIAL COUNTS.

In order to control bacteria we must be able to measure their numbers. We can see whether they are present in fairly large numbers under the microscope, but it would be quite impossible to say that there were none in a sample by looking at it through the microscope and very difficult to count their number. What we do is to add a definite quantity of the liquor or sweet water, usually 1 c.c., or cubic centimetre, 15 to 20 drops, to some transparent bacteria food which will set into a jelly in a flat glass dish. The dish is covered up to prevent stray bacteria entering and is placed in a warm cupboard for one, two or three days, after which it is examined. Each original bacterium has now produced a family of many thousands and each family is visible as a spot. These spots are counted, which gives us the number of bacteria in the original sample.

OTHER TESTS.

Apart from sugar analysis, which will be discussed in the next chapter, there are many tests which have to be done to many different materials. The correct treatment of our water for the boilers requires many tests for ·pH and for various salts. All materials such as char and lime which are going to come into contact with our liquors must be tested for poisons as well as tested to see that they are of the correct quality that we have specified when they were bought. Coal must be tested for heating power and for water. Cardboard and paper used for packing must be tested for poisons. Tinplate must be tested to see that the steel has a proper coating of tin on it, etc., etc.

CHAPTER 4.   SUGAR ANALYSIS.

With thy long-levell'd rule of streaming light.

MILTON—Comus—1634.

Properties of the Sugars—Polarised Light—The Polariscope—"Pol"—Polarisation of Sucrose and Invert—Clerget Method of Measuring Sucrose—Measurement of Invert Sugar—"Sample" and "Solids"—"Wet" and "Dry"—Polarisation for Sucrose—Sweet Testing.

The main text of this chapter contains no reference to the illustrations, which carry their own explanations, printed in italics.

PROPERTIES OF THE SUGARS.

The sugars are, from a chemical point of view, rather complex substances, and it is very fortunate for the sugar industry that they have certain simple properties which enable their kinds and amounts to be measured reasonably quickly and fairly accurately.   The first of these properties is the action that all sugar solutions have upon a certain kind of light, and the second is the action that certain of them have on certain metallic salts.   We will consider the action that they have on light first as it is a property that they all possess and is the most important part of sugar analysis.

POLARISED LIGHT.

Light is a wave motion which travels incredibly fast—in air at about 186,000 miles a second.   The wave is a curious complicated thing not like a simple wave on a liquid surface but a waving in all directions at right angles to the direction in which the wave is travelling.   Let us try to get a picture of the way the light wave moves.   Fasten a long rope to a hook in a wall and hold the other end of the rope with the rope stretched tight.   Now give the hand holding the rope a sharp up and down movement.   A wave will travel along the rope in an up and down direction.   Now shake the hand to and fro and a wave will travel along the rope waving in a horizontal direction.   Now shake the hand half way between up and down and to and fro and the wave will travel along at an angle of 45°.   A ray of light is like a bundle of such ropes all waving at different angles.   Certain materials have the curious property of passing light waves that are waving in one particular direction.   Iceland Spar is the most important of these materials.   Iceland spar

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is a form of crystallised chalk which is found in certain parts of the world, Iceland being the most important. When a beam of light enters Iceland spar it is refracted (see page 44) into two separate beams or rays. One of these rays is the ordinary ray and is refracted quite a lot and consists of ordinary light waving in all directions. The other ray is called the " polarised " ray and is bent or refracted through a much smaller angle and consists of light waving in only one direction. This light is called " plane-polarised "—a rotten name—because it is waving in only one plane and therefore has definite poles or directions in which it waves. The name does not matter ; what matters is that we should understand that it is waving in one direction only. The sugars have the strange property of twisting or " rotating " the wave direction or the poles of this polarised light. That is to say, if the polarised ray from a piece of Iceland spar is passed through a sugar solution the wave which was waving, say, horizontally will be twisted or rotated until it is waving, say, vertically. The stronger the sugar solution the more the ray will be twisted and if solutions containing the same amount of sugar are compared it will be found that the different sugars twist the ray through different angles. The instrument which measures the twist of the polarised light is called a " polariscope," and is the most important instrument in a sugar laboratory.

THE POLARISCOPE.

The curious properties of Iceland spar have been the subject of much work by many famous men for two hundred and fifty years. A great deal of work was done before the crude instrument invented by the Frenchman, Biot, in 1840, became the accurate and practical instrument that we use to-day and know as the polariscope. All the success that attended the work of the many scientists who experimented with the polariscope was due originally to a German, Nicol, who as early as 1829 devised a prism of Iceland spar which refracts the ordinary ray right out of the prism sideways leaving only the polarised ray to pass straight through.

The polariscope consists of a metal tube with a Nicol prism at either end. A light is shone into one end of the tube. It there enters the first Nicol prism, which is called the polariser. This polariser prism eliminates the ordinary ray and leaves the polarised ray to shine on down the tube.

At the other end of the tube near the eyepiece is the second Nicol prism called the analyser. Between the two prisms is a tube of glass, closed at each end by glass discs, into which is put the sugar solution to be tested. The analyser prism is so mounted that it can be rotated. When the ray of polarised light from the first or polariser prism passes through the sugar solution it is twisted.

Now a ray of polarised light can only pass through the second or analyser prism if the light is waving in the direction in which the second prism would have let it pass had the second prism been in front. If the analyser prism be turned to and fro a position will be found in which it will allow the ray from the sugar solution to pass through. This is a bit difficult to follow. Imagine that the first—polariser—prism is a vertical slot, say one-sixteenth inch wide and one inch long in a piece of material one inch thick. Then the only waves that can get through are those that are waving up and down. Imagine that the second—analyser—prism is a similar slot. No appreciable waves will get through the second prism unless its slot is also vertical. Now suppose a sugar solution is placed in the tube between the two slots. The up and down wave which has passed through the first slot will be twisted by the sugar solution until it is waving, say, horizontally. If the second slot is twisted about it will be found that the wave can get through if the slot is twisted until it is horizontal, whereas if the second slot is at the vertical the wave will be flattened right out. Now this means that when we look through the eyepiece of the polariscope when the analyser prism is in such a position that the light waves are " flattened right out " hardly any light will be seen, but as the analyser prism is rotated the light will get brighter and brighter until it is at its brightest when the analyser allows the wave to pass through undisturbed. By attaching a pointer to the analyser prism and fixing a scale to the instrument we can measure how much the analyser prism has had to be turned to let the light through in greatest quantity, in other words the scale will show us by how much the sugar solution has twisted our ray of polarised light. In practice it was found that it was much easier to see when the light was darkest than when it was brightest, that is to say it is easier to measure the point at which the analyser prism " flattens the wave right out " than where it lets the greatest amount of light through. Start with no sugar in the tube. Turn the eyepiece until the light is at its weakest. Then place the sugar solution in the tube when it will be seen that the light is now rather brighter. Turn the analyser prism about until the light is again at its weakest. Then the amount by which the analyser has had to be turned is the amount by which the sugar has twisted the ray of light. This is what we do when we take a measurement on the polariscope.

The finding of the darkest point by turning the analyser prism proved to be very uncertain and inaccurate, and a great deal of work was done to try and find a more sensitive method of measuring the twist of the rays. A Frenchman, Soleil, and an Irishman, Jellett, were responsible for the very clever device which made the polariscope an instrument of real precision. This improvement dated from about 1860.

Instead of shining one ray of polarised light through the sugar solution two rays alongside each other are shone down the tube. These two rays are obtained by making the polariser in two parts so that the two rays are waving at slightly different angles to each other. When the analyser is turned so that one ray is bright the other one will be dark. If the analyser is now turned a little the dark ray will become bright and the light ray will become dark. There will be a point midway when both rays will shine faintly with exactly the same brightness. This is a very easy point to measure and is used as the measuring point in all modern instruments. When the two rays pass through a sugar solution they will both be twisted by the same amount and the analyser prism can be turned until the brightness of the two rays exactly matches. This point will give a very reliable indication of the amount by which the sugar has twisted the rays.

In some modern instruments three rays are used. The two outer rays waving in one same direction and the inner one waving in a slightly different direction. It is found that the matching of this " sandwich " of brightness is even easier and more reliable than the matching of two halves.

Nowadays the Nicol analyser prism has been modified by an analyser made of quartz. There is no need for us to consider this improvement. It in no way affects the principle of the instrument and might be unnecessarily muddling.

THE POLARISCOPE.

A ray of light is a complicated wave. Some sort of idea of it can be got by trying to build it up in imagination, by putting together a lot of simple waves.

Fig. 15
Vertical Wave.

Fig. 15 shows a wave waving vertically up and down.   Fig. 16 shows a wave waving horizontally from side to side, while Fig. 17 shows a wave waving obliquely at an angle of about 45°.
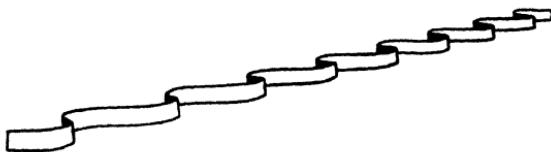
Fig. 16
Horizontal Wave.

Fig. 17
Oblique Wave.

Now imagine other waves waving at all the other intermediate angles and bundle all these waves together and we have got something like a ray of light.

In Chapter 2 we learnt that a ray of light is bent or refracted when passing from one substance into another.   Iceland Spar—a form of crystallised chalk—has the curious property of refracting a ray of light into two parts.   The ordinary ray, waving in all directions, is refracted quite a lot, but the other or " extraordinary " ray is refracted a very little.   The " extraordinary " ray is truly extraordinary because its wave is waving in one direction only.   We sugar people are particularly interested in this extraordinary ray (which is also called the " polarised " ray) because it is influenced by the sugars.   Before we can use the polarised ray we must get rid of the ordinary ray altogether. This is done by using a prism invented by a German called Nicol.

In this prism, which is shown diagrammatically in Fig. 18, a block of Iceland Spar is cut to the shape shown and then cut in half diagonally across its blunt corners. The two triangular pieces are then cemented together again with Canada Balsam. If a ray of light enters

ORDINARY RAY
REFLECTED BY
BALSAM FILM

ORDINARY RAY
REFRACTED
OUT

POLARISED RAY
GOES STRAIGHT ON

ICELAND SPAR
PRISM

90°

LIGHT RAY WAVING
(IN ALL DIRECTIONS

CANADA BALSAM
CEMENT FILM

REFRACTED
INTO TWO RAYS

19°   POLARISED RAY PASSES
THROUGH BALSAM FILM
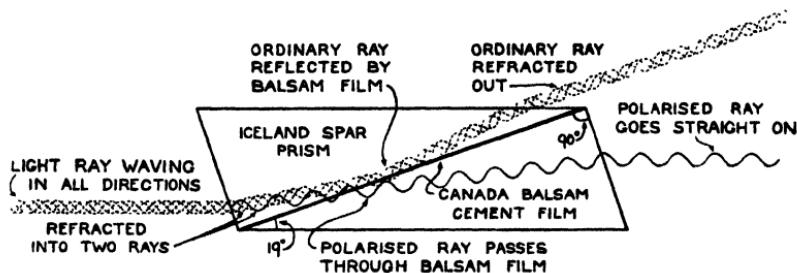
Fig. 18
Nicol Prism.

the Nicol prism from the left it is refracted into two rays, ordinary and polarised. As the ordinary ray is refracted quite a lot it strikes the Balsam film at a very oblique angle and is reflected right away just like the very oblique rays in the refractometer. But the polarised ray being much less refracted strikes the Balsam film at a less oblique angle and is able to pass through it. On leaving the right-hand edge of the prism the polarised ray is refracted straight again so that it goes on in the same straight line as the complete ray originally entered the prism. A Nicol prism therefore delivers just one ray of polarised light waving in one direction.
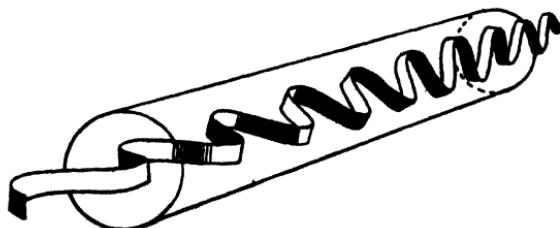
Fig. 19
Right-Handed Rotation.

If a ray of polarised light is passed through a sugar solution the ray is twisted or " rotated " so that it is waving at a different angle. Each kind of sugar twists the ray a different amount and some sugars twist the ray to the right, for example sucrose and dextrose, while some, such as invert and lœvulose, twist it to the left. This twisting is shown diagrammatically in Figs. 19 and 20.
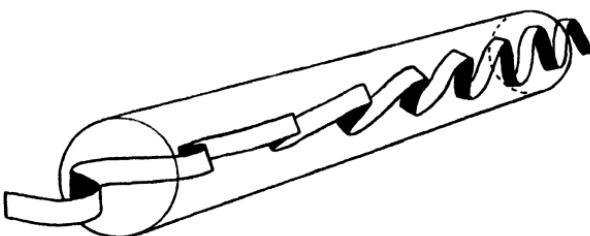
Fig. 20
Left-Handed Rotation.

If we could measure the way the ray has been twisted and the amount of the twist, we ought to be able to tell how much of a particular kind of sugar we had in the solution. This is what the instrument called the polariscope does.

The principle on which the polariscope works is shown in Fig. 21. Light enters the first Nicol prism, called the polariser prism, from the right. The ordinary ray is refracted out of the polariser and is absorbed by the black paint inside the tube which forms the frame of the instrument (this tube in which the prisms and sample tube are all mounted, is not shown in the diagram). The polarised ray, waving in only one direction, goes straight on along the instrument, passing through a tube closed with glass end discs and containing the sample of sugar solution to be tested. The test solution is always made of the same standard strength. The sugar solution gives the ray a twist depending on the particular sugar and its purity. A second Nicol prism, called the analyser prism, is mounted at the near or left-hand end of the instrument in such a way that it can be rotated or twisted. The polarised ray can only pass through the analyser prism if the prism is turned to one particular angle. A pointer is attached to the analyser prism and works on a scale to indicate the amount and direction of the twist of the ray.

NICOL ANALYSER PRISM
WILL ONLY PASS LIGHT IF
ITS AXIS IS IN LINE WITH
WAVE OF POLARISED RAY

LAMP

ORDINARY
LIGHT RAYS

NICOL POLARISER
PRISM ONLY PASSES
POLARISED RAY WAV-
ING IN ONE DIRECTION

SUGAR
SOLUTION IN GLASS
TUBE TWISTS RAY

EYE

SCALE FOR
MEASURING TWIST
OF RAY
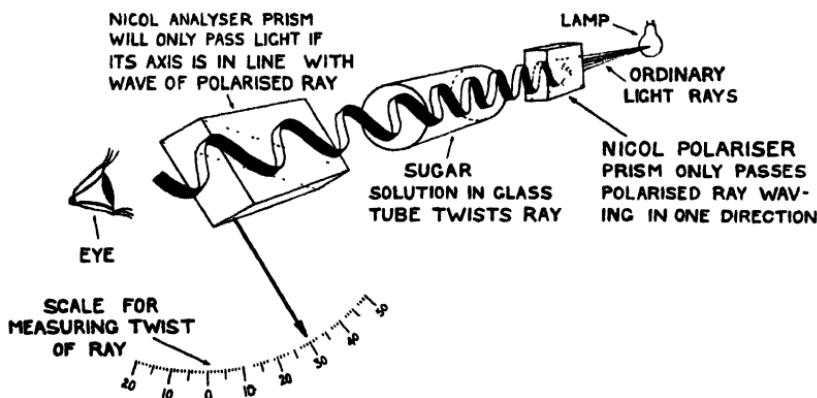
Fig. 21
Diagram of the Principle of the Polariscope.

    Actually it is very difficult to measure with the eye the exact position in which the analyser is letting most light through. A very clever arrangement has been devised to enable the exact measuring position to be found quite easily. Two polariser prisms are used and they are so mounted in the instrument that they send two polarised rays along the instrument waving at slightly different angles. If the analyser prism is turned so that one ray, say the right-hand one, is brightest the other ray will be dull and the eye will see something like the view shown in Fig. 22.
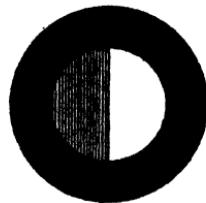
Fig. 22
Half Shadow Polariscope.

    If the analyser prism is turned a little the left-hand ray can be made to appear the brightest and the right-hand half will become dim, as in Fig. 23.

Midway between these two positions there will be a position to which the analyser can be turned when both rays will shine with equal
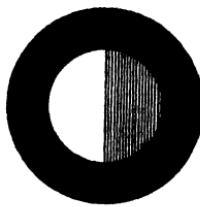
Fig. 23
Half Shadow Polariscope.

brightness and both halves of the view down the instrument will look exactly alike. This position is shown in Fig. 24.
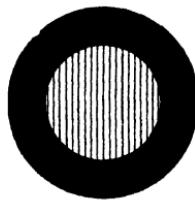
Fig. 24
Half Shadow Polariscope.

This position of the analyser is very easy to find and is used as the measuring point. With no sugar solution in the sample tube, the analyser is turned until the light shining down the instrument looks like Fig. 24. The sample to be tested is then put in the tube and the analyser is turned until the light again looks as in Fig. 24. The amount by which the analyser has been turned is read off the scale on the instrument and this figure is called the " polarisation."

In modern instruments a wedge of quartz has replaced the analyser prism. This refinement in no way affects the principle of the instrument, and need not be described in this book.

"POL."

To measure how much the analyser has been moved in the polariscope in order to neutralise the twist given to the light by the sugar solution it is necessary to have a scale. Nearly all scales on scientific instruments are made by finding the two end points and dividing the space between these two points into a number of equal parts. For example, when the scale on an ordinary mercury-in-glass thermometer is made the thermometer is put into melting ice and a mark is made on the stem at the place where the mercury stands. The thermometer is then put into boiling water and another mark is made at the mercury level. The space between the two marks is divided into 100 equal parts. Provided that the glass tube is the same diameter all the way up we will now have an accurate thermometer reading between 0° and 100° Centigrade. The scale for the polariscope is made in a similar way. The two halves of the light coming through are adjusted until their brightness exactly matches when there is no sugar solution in the tube. The position of the pointer is then marked on the scale. Then a reading is taken when there is a definite quantity of pure sugar dissolved in a definite quantity of pure water. The space between the two points is marked off into 100 equal parts. If a solution of an impure sugar is made up using the same weight of sugar made to the same volume of solution as was used in the solution used to mark off the scale, the reading on the scale will show us just how much pure sugar there was in our sample of impure sugar. This figure, which we obtain from the polariscope, is called the " polarisation " or "pol." If we take the pol of a raw beet sugar we shall probably find that we shall have to move the analyser to such a position that the pointer will show about 96. This means that every 100 tons, pounds or ounces of raw sugar contained 96 tons, pounds or ounces of pure sugar. The remaining four parts being made up of ash, organic matter and water. In the same way we can measure how much sugar there is in a liquor, syrup or massecuite. The pol figure is always spoken of as so many " degrees."

POLARISATION OF SUCROSE AND INVERT.

So far we have been using the word sugar, in connection with polarisation, as though there were only one kind, or as though all kinds of sugar behaved the same way in the polariscope. In Chapter 1. we have learnt that there are two kinds of sugar with which we are concerned, namely sucrose and invert sugar. These two sugars do not behave at all in the same way towards a beam of polarised light. Sucrose twists it to the right while invert twists it to the left, but to a smaller extent than sucrose twists it. This clearly introduces a serious complication. If we take the pol of a

syrup containing both sucrose and invert, the pol we have got is due to the combined effect of the right hand twist of the sucrose and the left-hand twist of the invert. Where pure sucrose gives a right hand or + twist of 100 pure invert gives a left hand or − twist of 30. If we had a solution containing 23% sucrose and 77% invert we should get a pol of + 23 from the sucrose and a pol of 77% of 30 or − 23 from the invert and our pol would be 0 for the mixed solution. In the case of beet sugar there is practically never any invert sugar present and the pol gives the real percentage of sucrose present, but cane sugars which contain invert can clearly give what would be very false results if we had not got some way of getting round the difficulty.

THE CLERGET METHOD OF MEASURING SUCROSE.

A Frenchman, called Clerget, in 1849 invented a method whereby the sucrose in a sugar solution could be measured on the polariscope regardless of the amount of invert sugar present. Pure sucrose made into a standard solution polarises $+100°$. Pure invert sugar made into a standard solution polarises $- 30°$. As has been explained in the previous chapter, 57 parts of sucrose combine with 3 parts of water during inversion to become 60 parts of invert sugar. If we make up a solution of sucrose by dissolving 26 parts of sugar in standard amount of water it will polarise 100° to the right. Now, if we invert the sucrose in this solution completely we shall have more than 26 parts of invert. We shall have $26 \times \frac{60}{57}$. If we now take the polarisation of this solution it will polarise more than 30 to the left because there are more than 26 parts of invert in it. It will polarise $30 \times \frac{60}{57} = 31.6$ to the left. So that by inverting sucrose which polarised + 100° we convert the polarisation to $- 31.6°$. That is to say that by inversion the polarisation has shifted 131.6 to the left. So we can say that every part of sucrose which polarises + 1° will, when inverted, polarise 1.316° more to the left. This is the principle on which the Clerget method works. The pol of the original sample is measured and the sucrose is then completely inverted by means of a little hydrochloric acid and the pol is measured again. Then the amount by which the polarisation has shifted to the left is divided by 1.316 and the result is the amount of sucrose in the original sample. For example, suppose the direct polarisation of a sample of raw cane sugar is 92.3 and the polarisation after inversion is − 29.8, then the total shift to the left is 92.3 + 29.8 = 122.1. Dividing this by 1.316 we get 92.8 which is the sucrose in the original sample. In practice all sorts of refinements are introduced to compensate for the destruction of invert sugar during inversion and other things that we need not bother about. The only important result of these things is that the theoretical factor of 1.316 is not correct. The actual factor that we use is 1.3266.

MEASUREMENT OF INVERT SUGAR.

It might be thought that the Clerget double polarisation for measuring the sucrose would give us the amount of invert sugar. This is to some extent the case but such a measurement would be liable to considerable error. Take the case above, the polarisation of the sucrose alone would have shown 92·8, whereas the actual direct polarisation was 92·3 which means that the invert must have been exercising a left-handed polarisation of − 0·5. One hundred parts of invert polarise − 30 so that a polarisation of − 0·5 represents an invert of $0·5 \times \frac{100}{30} = 1·666$. That is to say the invert is $3\frac{1}{3}$ times the difference in polarisation. If there was an error of ·1 in each of the polarisations the combined error, when multiplied by 3·33 might easily amount to nearly the whole of the invert sugar, so that this is quite an inaccurate way of testing for invert. Another source of error is that, as has been stated in Chapter 1., invert sugar consists of a mixture of equal parts of two sugars, dextrose and lævulose. Pure dextrose polarises + 80 and pure lævulose polarises − 140. Half a part of each will polarise + 40 and − 70 or − 30 when measured together. Invert sugar consists of equal parts of the two sugars only when freshly inverted. Lævulose is destroyed more easily than dextrose and raw sugars which may have been kept for many months in conditions favouring lævulose destruction often contain more dextrose than lævulose. The double polarisation method can tell us nothing about this and might cause a totally wrong figure to be put on the invert if it were assumed that the dextrose and lævulose were present in exactly equal proportions. It is therefore necessary to measure the invert another way. Fortunately invert sugar, as has been mentioned already, has an action on certain metallic salts which enables us to measure its quantity easily and accurately without it being necessary to know in what proportions the two invert sugars are present. Invert sugar has the property of throwing down red copper oxide from a rather elaborate solution of salts called Fehling's solution, after its inventor. It will only muddle us if we worry about the exact make-up of Fehling's solution. All we need to know is that it contains copper and is a deep blue colour. If invert sugar is added to the blue Fehling's solution the copper is thrown down as a red precipitate and the blue colour gradually fades. When all the copper has been thrown down the solution becomes colourless. Sucrose has no effect on Fehling's solution.

The way the test for invert is done is as follows. A certain definite quantity of Fehling's solution is taken and brought to the boil. To this solution is added, drop by drop, a solution of a known amount of pure invert sugar. After adding a certain amount of the invert sugar all the colour will have been removed from the Fehling, showing that all the copper has been thrown out. This part of the

test need only be done occasionally to measure the strength of our Fehling solution. When a sample of sugar is to be tested for invert, a weighed quantity is dissolved in a definite amount of water and added, drop by drop, to a definite known quantity of Fehling's solution. Now we know from our previous test how much invert sugar will be necessary to bring down all the copper in this amount of Fehling, so, as soon as all the colour disappears from the solution we know that the sugar solution that we have added must contain the known amount of invert necessary to bring out the copper from the Fehling.

There are other ways of testing for invert. It is not necessary to describe them. The most important is the method used for testing for very small traces of invert such as we have in our refined sugar. For this purpose it is necessary to be able to measure little quantities as small as 0.001%, and a dye, methylene blue, is used for this test. (Methylene blue is also used as an indicator with Fehling).

"SAMPLE" AND "SOLIDS"—"WET" AND "DRY."

We sometimes talk of there being so much sucrose " on sample " or so much sucrose " wet." We also talk about so much ash " on solids " or so much ash " dry." It is necessary to understand just what these two terms mean. Our object in the refinery is to remove impurities from the sucrose. It is therefore essential to know with how much impurity the sucrose is contaminated. All the syrups and liquors throughout the refinery are just solutions of sucrose of varying purity in varying amounts of water. Now the water is not an impurity, it is merely a carrier of sugar. By dissolving sugar in water we are able to carry the sugar through a very fine filter. The finer the filter the more water must we use to carry the sugar through. All the water that we use in this way is going to be evaporated in the pans later and has no effect on the purity or otherwise of our sugar. We therefore disregard the water in most analyses or tests that we do for the control of our process, and we consider the amounts of sucrose and of the amounts of the various impurities only with reference to the solids in the solution. An example should make the matter clear. Suppose we have a sample of a sugar liquor which we test first for invert sugar by means of Fehling's copper solution and then for sucrose by the polariscope, and then for ash by the electrical or the burning method, and then for water by means of the Brix spindle. We get results like the following, say :—

Sucrose .	.	.	.	65·0 parts
Invert Sugar	.	.	.	·3 ,,
Ash .	.	.	.	·7 ,,
Organic Matter	.	.	.	1·0 ,,
Water .	.	.	.	33·0 ,,
				100·0

Suppose now that we have another sample which when tested gives the following analysis :

Sucrose .	.	.	.	.	81·0 parts
Invert Sugar .		.	.	.	·42 ,,
Ash	.	.	.	.	·83 ,,
Organic Matter		.	.	.	1·25 ,,
Water .	.	.	.	.	16·5 ,,
					100·00

Suppose these samples have come from a part of the process where our main object is the elimination of ash. One sample has an ash of ·7 while the ash of the other is ·83. It would be entirely wrong to say that there was more ash in the second than in the first, because there is less water in the second than in the first. What we want to do is to find out whether there is more or less ash in the *dry solids* that are in solution in the two samples. These two analyses already given are the analyses " on sample " or " wet," whereas what we want to know is the analysis of the dissolved dry solids. The water is of no importance as regards the purity of the sample, it is only important in so far as it will have to be evaporated later and it is necessary to have the correct amount of water in a solution in order that it should flow easily through the various pieces of plant. We get our analysis " on solids " by forgetting the water. In our first analysis we add all the solids together and we find that they add up to 67 parts, of which 65 are sucrose. In the second analysis we see that the solids add up to 83·5, of which 81 are sucrose. If we calculate what the sucrose would be on 100 parts of solids, by multiplying by 100 and dividing by the amount of the solids we get the " sucrose on dry solids." In both cases we find that the sucrose is 97·0. If we take any of the other constituents and calculate them back to solids we find that we get the same figure on each sample. The analysis " on Solids " or " Dry " is :

Sucrose .	.	.	.	.	.	97·0
Invert Sugar .		.	.	.	.	·5
Ash	.	.	.	.	.	1·0
Organic Matter		.	.	.	.	1·5
						100·0

The only difference between the two samples is that there was more water in one than in the other and without calculation it is impossible to compare their composition. The only figure that we really want to know " on sample " or " wet " is the amount of water. All the other figures are useless for comparison and control unless they are the figures " on solids " or " dry."

POLARISATION FOR SUCROSE.

Clerget's method of double polarisation for sucrose is a long and cumbersome business. It gives an accurate result regardless of the amount and composition of the invert sugar present. But it does not give us the amount of invert sugar in the sample. The invert must be measured by means of Fehling's copper solution. Now we know that invert sugar affects the polarisation of the sucrose in the sample. If we knew the amount of the invert and were sure that it consisted of equal parts of dextrose and lævulose we should be able to say that the invert sugar had had a certain definite effect on the polarisation. Suppose we know that a certain sample has 1·0% of invert in it and we know that this particular invert polarises correctly, namely, − 30 for 100% invert. Then we can say definitely that the direct polarisation will have a left-handed component due to the invert of − 0·3. If the direct polarisation was, say, 97·7, then the true polarisation due to the sucrose would have been 97·7 + ·3 = 98·0. So that the sucrose in the sample was 98%. But Fehling's test does not tell us whether the invert is present in exactly equal quantities of dextrose and lævulose, so we have to use some way of finding out just what the effect of the particular invert sugar that we have present is in order to use this short cut method of polarising for sucrose. Molasses consists of the concentrated impurities in our raw sugar together with some sucrose that it did not pay us to extract. We measure the invert sugar in our molasses by means of Fehling's copper solution. We measure the amount of sucrose by means of Clerget's double polarisation method. We thus know not only the quantity of invert sugar present but its exact effect upon the polarisation. We find in practice that the left-handed effect of invert sugar in a raw sugar is never the true figure of ·33 times the amount of invert sugar. This polarisation effect figure for invert sugar varies from as low as ·19 to a maximum of about ·31. As explained above the reason is that the lævulose which gives invert sugar its left-handed polarisation is destroyed more easily than dextrose, and most sugars which contain invert sugar gradually lose lævulose.

For process control, where extreme accuracy is not needed we measure the invert sugar by means of Fehling's Solution and divide the invert thus obtained by the "invert factor" fof the molasses, which we periodically find out as just explained. We can by this means find the sucrose by adding the invert effect on to the direct polarisation. The invert factor is usually about ·25.

SWEET TESTING.

The polariscope will not measures the amounts of very small traces of sugar in a solution. There are modifications of Fehling's

test which can detect quite small traces of invert sugar, but this will not measure sucrose. Fortunately there is an excellent test for both sugars which is accurate and very quick. We use this test on all our drain waters, condenser waters and boiler feed waters, where we want to be able to detect any leak or contamination by sugar instantly. Some 1,500 tons of water pass from our condensers to the river every hour in each of our refineries. If the percentage of sugar in the condenser water was as little as 0·01% we should be losing over a ton of sugar per shift into the river. The test we use is very accurate and sensitive. Done quickly and with very little care, it will detect with fair certainty one part of sugar in 100,000 parts of water. Done carefully and more slowly it can detect one part of sugar in 1,000,000 parts of water.

The test for small traces of sugar, or "sweet" as we call it, was invented by Molisch and consists in adding a little strong sulphuric acid to the sample water and following this with a few drops of an oily substance called alpha-naphthol, which is produced from coal tar. If there is sugar present there is a violet colouration of the liquid, the greater the amount of sugar the stronger the colour. By testing water samples to which known amounts of sugar have been added a scale of violet tints can be prepared which correspond to definite amounts of sugar present.

CHAPTER 5.   HEAT AND STEAM.

Soon shall thy arm, unconquered steam ! afar
Drag the slow barge, or drive the rapid car ;
Or on wide waving wings expanded bear,
The flying chariot through the field of air.

<div align="right">E. DARWIN—The Botanic Garden—1792.</div>

Convenience of Steam — Specific Heat — Latent Heat — Sensible Heat —
Superheat—Temperature of Boiling Point—Total Heat—Volume of Steam—
Steam Table—Saturated and Superheated Steam—Wiredrawing—Desuper-
heating—Flash—Steam Traps—Evaporation—Condenser Loss—Multiple
Effect Principle—Power from Steam—The Steam Turbine—Radiation Loss—
Lagging—Aluminium Paint.

CONVENIENCE OF STEAM.

All over the refinery we require heat.   Heat for warming the
magma, for melting the sugar, for heating the liquor, for keeping
tanks warm, for boiling the pans, for heating the granulators, etc.,
etc.   Imagine the dirt, dust, flues, ashes, chimneys etc. that would
be needed if we had a separate fire for all these things.   It is
necessary to be able to bring easily controlled heat in a clean
convenient form to all parts of the process.   Steam is a most
admirable medium for the purpose.   Steam contains a tremendous
amount of heat.   The quantity of heat which can be conveyed
along quite a small steam pipe is staggering when thought about.
The eight inch steam pipe taking steam to one of the Plaistow
Wharf turbines can carry all the heat resulting from the burning of
seven tons of coal per hour.   The reason that steam is such a good
heat carrier is because it has a fairly high " specific " heat and,
more important, such a very high " latent " heat.   We must try to
understand what the different sorts of heat are.

SPECIFIC HEAT.

The specific heat of a substance is the amount of heat that
must be added to it to get a certain rise of temperature.   It is a
curious fact that every substance requires a different amount of
heat to raise its temperature by the same amount, and this variation
may be very large.

Suppose we have five similar glasses each containing an equal
weight of five different liquids, namely : Water, Alcohol, Glycerine,

<div align="center">87</div>

" Pyrene " and Mercury. Now suppose that we add an equal amount of heat to each of these by, for example, dropping into each glass one of a number of equal sized pieces of metal which have been heated to the same temperature in an oven, or by burning a thimbleful of methylated spirit under each glass in such a way that none of the heat is lost. Assume that the amount of heat that is added is sufficient to raise the temperature of the water by 10°C. Then the alcohol would be raised by 16°C, the Glycerine 17°C, the liquid from a " Pyrene " fire extinguisher—carbon tetrachloride—by 50°C, while the mercury would be heated up by 303°C.

The specific heat of water is 1·0, of alcohol ·63, of glycerine ·59, of carbon tetrachloride ·20, and of mercury ·033. These figures are the Heat Units needed to raise 1-lb. of the liquid 1° in temperature.

Gases also show striking variations in their specific heats. If we try our heat adding experiment on equal *weights* of gases we should get results something like this : Air would be heated up 42°C, steam would be heated 21°C, ammonia 19°C, while hydrogen would only be raised by not quite 3°C.

The specific heat of air is ·238, of steam ·47, of ammonia ·52, and of hydrogen 3·33.

Specific heat is not constant, but changes with temperature. The figures given above are for ordinary room temperatures.

LATENT HEAT.

Suppose wc have one pound of water at room temperature, say 15°C. Now suppose we add small quantities of heat to this water. Each little " piece " of heat we will suppose to be enough to raise the temperature of our pound of water by 1°C. Such a small " piece " of heat is called a pound-calorie (Latin, calor—heat) or Centigrade Heat Unit or C.H.U. If we were using the Fahrenheit scale, the little " piece " of heat needed to raise one pound of water 1° Fahrenheit would be less than 1 C.H.U. It would actually be $\frac{5}{9}$ of one C.H.U. and is called a B.Th.U. or British Thermal Unit. To raise our pound of water to boiling point, that is 100°C, from 15°C we have to add 85 units of heat. When we have a pound of water at 100°C it is said to contain 100 Centigrade Heat Units or C.H.U.

What happens if we go on adding heat? We all know that the water boils and that its temperature stays at 100°C. Where is the heat going to if the temperature is not rising ? It is going into the steam and is necessary in order to break the water up into steam. If we were able to do a good accurate experiment we should find that each heat unit that we added would cause 1/539th pound of water to change into steam—in fact to change the whole pound of

water at 100°C into steam would require the addition of 539 C.H.U.

If we wish to turn the pound of steam back into water it can only be done by taking these 539 C.H.U. out of the steam by cooling it with something. This hidden heat which has to be put into water to turn it into steam and has to be taken out of steam to turn it back into water is called "latent" heat. Latent means lying hidden. The putting in or taking out of latent heat has no effect on the temperature. It is this latent heat that we use principally for heating and boiling liquors and syrups.

If we have one pound of steam at 100°C we can take out 539 heat units by condensing it back to water. That is to say we can heat 539 pounds of water up 1°C, or 53·9 pounds 10°C, with the latent heat in one pound of steam at water boiling point. This heat is that which is available by condensing our steam only, not by cooling the condensed water. It is the heat that we must remove to turn our steam from being steam at 100°C into water at 100°C. Suppose we use this pound of steam in a Hawley boiler, which raises water to exactly its boiling point automatically. Water enters the Hawley boiler from the pan vapour heaters at, say, 60°C, each pound of water will therefore need 40 C.H.U. to raise it to boiling point. The pound of steam that is to be condensed has 539 C.H.U. to get rid of, so it will heat 539 divided by 40, or 13½ pounds of water from 60°C to 100°C.

SENSIBLE HEAT.

The great amount of heat that has to be put into water to change it into steam is hidden. It causes no increase in temperature. Only our memory tells us that it has been put in at all. On the other hand the heat that we add to cold water to bring it to the boil can be felt as a rise in temperature by our senses. This heat is called sensible heat because we can appreciate it with our senses. So that the 85 C.H.U. which we added to our pound of water to bring it from room temperature to boiling point are units of sensible heat, and water at boiling point has 100 units of sensible heat in it, because heat is measured from 0°C, the freezing point of water.

SUPERHEAT.

Now suppose that after adding sufficient latent heat, namely 539 C.H.U., to our pound of water to turn it all into steam, we go on adding heat. This will cause a rise in temperature of the steam and this extra heat added to the steam is called superheat. Owing to the specific heat of steam being only a little less than half that of water, we should find, if we could carry on with our heat-adding experiment, that by adding 24 C.H.U. the temperature of the pound

of steam would rise 50°C. (This ratio of 12 C.H.U. to 25°C temperature rise does not hold good for all conditions of steam because the specific heat changes with temperature.)

TEMPERATURE OF BOILING POINT.

Water at atmospheric pressure boils at 100°C. If the pressure on the surface of the water is reduced—by boiling in a vacuum—the water boils at a lower temperature. If the pressure on the surface of the liquid is increased—by boiling under pressure as in a steam boiler—the water must be raised to a higher temperature before it will boil. This is just what one might expect to be the case. The higher pressure is more difficult to overcome and a higher temperature is necessary. The boiling temperatures of water at different pressures below and above atmospheric pressure are shown in the following table.

Pressure.						*Boiling Point.* °C.
29·33 inches vacuum		...	...	...	20
27·75 ,, ,,		...	...	...	40
24·0 ,, ,,		...	...	...	60
16·0 ,, ,,		...	...	...	80
Atmospheric	...	...	...	...	100
54-lb. sq. in.	...	...	...	...	150
210-lb. ,,	...	...	...	...	200
560-lb. ,,	...	...	...	...	250
1230-lb. ,,	...	...	...	...	300

TOTAL HEAT.

The total heat in a pound of steam is made up of three parts, the sensible heat put into water, the latent heat of evaporation and the superheat, if any, of the steam. From the table in the previous section it will be seen that the amount of sensible heat at different pressures differs greatly. We see from this table that the sensible heat in steam at 210-lb. pressure is ten times that in vapour at 29·33 inches of vacuum. The latent heat also changes with the pressure, but in the opposite direction to the sensible heat. The superheat changes with temperature because the specific heat of steam changes. with temperature and pressure. None of the rules governing these changes in the amount of heat is simple enough to carry in the mind. Tables have therefore been worked out which give the total heat in steam at all states of temperature and pressure likely to be met with in practice.

VOLUME OF STEAM.

The space occupied by steam at different pressures and temperatures must be known in order to provide pipes of adequate size. Almost every substance (except ice and water below 4°C) gets bigger when heated. Once the " coefficient of thermal expansion," a rather grand phrase which means the amount by which the thing gets bigger for each degree of temperature rise, is known, the volume can be worked out. As water is heated it expands slowly until it becomes steam when it increases in volume enormously. Steam at 100°C occupies nearly 1700 times the volume occupied by the water before it boiled. The more steam is superheated the larger is the volume occupied. Clearly the higher the pressure on the steam the smaller the volume. The volume of steam is fairly easy to work out, but as we have to consult a table to get the heat, it is usual to put the volume into the table as well. A very small steam table is given here (Table VI.) and it shows the sensible heat, latent heat and total heat in saturated (or unsuperheated) steam ; the total heat only for superheated steam ; the volume of saturated steam ; and the boiling point at each of the pressures given. This little steam table contains all the information necessary for fully appreciating all the steam conditions in the refinery. It will be noticed that the sensible heat does not quite follow the temperature. This is due to the specific heat of water changing slightly at high temperatures. The total heat of saturated steam is greatest at 400-lb. sq. in.

SATURATED AND SUPERHEATED STEAM.

When steam exists at the water-boiling temperature corresponding to the pressure of the steam, it is said to be "saturated"— that is to say it contains no liquid water and no superheat. Saturated steam is not in a good state to use in an engine or turbine. When steam does work in an engine or turbine it expands and loses heat because the engine is just a machine for absorbing expansion and turning the heat into work. [The fact that heat and work are interchangeable is not easy to explain, but we all know they must be. Suppose steam in a locomotive turns part of its heat into work by starting the train. If we want to stop the train we must apply the brakes, and the energy stored up in the moving train will be changed into heat which will appear in the brakes. If the train is stopped quickly the heat appearing at the brakes may be very great. We have all seen sparks flying off the brake shoes of a quickly stopping train. Again—if we have a supply of electricity which has been generated in a power station by the burning of coal, that is, by the use of heat, we can turn the electrical energy into work by making it drive an electric motor, or we can turn it back into heat by putting it into an electric radiator.]

TABLE VI.

PROPERTIES OF STEAM

PRESSURE Inches of vacuum or lb. sq. in. gauge	TEMPER-ATURE °C	SATURATED STEAM				SUPERHEATED STEAM TOTAL HEAT C.H.U. per lb at Temperatures:—						
		SENSIBLE HEAT C.H.U. per lb.	LATENT HEAT C.H.U. per lb.	TOTAL HEAT C.H.U. per lb.	VOLUME cu. ft. per lb.	100°C	150°C	200°C	250°C	300°C	350°C	400°C
28″	38	38	576	614	350	642	665	688	—	—	—	—
26″	52	52	568	620	180	642	665	688	711	—	—	—
24″	60	60	563	623	120	642	665	688	711	735	—	—
20″	72	72	556	628	75	641	665	688	711	735	759	—
10″	89	89	546	635	39	640	664	687	711	734	759	783
Atmos.	100	100	539	639	27	—	663	687	711	734	759	783
5lb.	108	108	534	642	20	—	663	686	711	734	758	782
20	126	126	522	648	12	—	661	685	710	733	758	782
45	145	146	509	655	7·2	—	657	683	708	732	757	781
70	158	159	499	658	5·2	—	—	681	706	731	756	781
100	170	172	489	661	3·9	—	—	679	705	730	755	780
150	186	188	476	664	2·8	—	—	673	702	728	753	779
200	198	201	465	666	2·1	—	—	668	698	726	752	777
250	208	212	456	668	1·7	—	—	—	695	723	750	776
300	217	222	447	669	1·5	—	—	—	691	721	748	775
650	259	269	398	667	·7	—	—	—	—	702	736	765

When steam is used in an engine or turbine it is very important that it should not contain water drops—however small. In a reciprocating engine water might cause knocking or even breakage if the amount of water was more than the clearance space between the piston and the cylinder head. In a turbine the drops of water would be blown through the blades like bullets and might blunt the blades or even strip them off. This may sound exaggerated but it is indeed true. Raindrops blown with a 50 m.p.h. wind hurt the face exceedingly. The steam in a turbine goes through the blades at speeds of between 1000 and 2000 m.p.h.—as fast as a rifle bullet. In an engine or turbine we try to take as much heat out of the steam as possible, and many engines exhaust their steam below saturation—that is to say with some water present. When steam expands and does work it cools down. If the steam was saturated when it cooled droplets of water would form. These drops will damage the blades of the turbine. If they are very small they will gradually wear the blades out until they are too thin and weak to withstand the forces acting on them.

Engines cannot use latent heat because when latent heat is given up condensation or contraction takes place and this is the opposite of expansion, and all engines work by absorbing the power of expansion of steam. If steam contains a lot of superheat, the latent heat, which cannot be used by an engine, represents a smaller fraction of the whole heat. If steam of fairly low pressure is highly superheated the steam will still be superheated when the engine exhausts it. This would clearly be wasteful from the power point of view. On the other hand very high pressure steam which can expand a great deal can usefully carry a very high amount of superheat. The best arrangement will clearly be to have just such an amount of superheat as will allow of little condensation in the engine but not so much as will cause the exhaust steam to be superheated.

In a sugar refinery we use all the exhaust steam from our turbines for process purposes and it does not matter if the turbine exhaust contains a little superheat. For many years it was thought that process steam should not contain superheat because superheated steam does not give up its heat so quickly to the metal walls of a heating coil as does saturated steam. But we have proved that in a calandria pan or evaporator, superheated steam parts with its heat as fast as saturated steam. This is probably because the incoming superheated steam instantly gives up its superheat to the film of water which has condensed on the tubes and partially evaporates it.

WIREDRAWING—DESUPERHEATING.

Saturated steam at 250-lb pressure has a temperature of 208°C

and 668 heat units per pound.   Saturated steam at 45-lb pressure
has a temperature of 145°C and contains 655 heat units.   If
saturated steam at 250-lb is blown through a reducing valve down
to 45-lb it cannot lose any heat—it has done no work so there is
nowhere for the heat to go—so that it will have 14 heat units in it
more than saturated steam at 45-lb should have. .These 14 heat
units will produce 29°C of superheat temperature.   The steam will
therefore be at a temperature of 174°C instead of 145°C. This super-
heating caused by lowering the pressure without taking any work
out is called " wiredrawing."   All steam pipes lose heat by radiation
and the wiredrawing caused by passing process steam through a
reducing valve helps to prevent condensation in the pipes, but
there are sometimes occasions when we wish to eliminate excessive
superheat due to wiredrawing.

    If we wish to remove superheat we pass the steam through a
small vessel, which is called a " desuperheater," and through which
distilled water is sprayed.   The superheat evaporates the sprayed
water.   If there is plenty of water all the superheat will be converted
into latent heat, but if there is only a little water all the water will
be evaporated, reducing the superheat by the amount corresponding
to the heat units used up.

<center>FLASH.</center>

    When steam at, say, 45-lb. pressure is used to boil a pan or to
heat any other piece of plant the steam condenses.   If the steam is
in a calandria or coil, the water that it becomes on condensation is
at the steam pressure and will be at the temperature corresponding
to the boiling point of the pressure, namely 145°C.   If this water
were allowed to run into a tank at atmospheric pressure, the water
would be 45° too hot and would give up this excess heat by
" flashing " part of the water into steam.   As there are 45 units of
surplus sensible heat and as the latent heat of steam at atmospheric
pressure is 539 it follows that 45/539 or one twelfth of the water
would flash off as steam.   This is much too much to waste.   High
pressure condensed water is therefore led into a flash tank which is
just a small vessel connected to a low pressure steam main.   The
water flashes down to the low pressure and most of the flash steam
is thereby saved.   If no suitable use can be made of the low pressure
flash steam, the superheated water is passed through a tubular heat
exchanger where its superheat is used to heat up some liquid that
requires heating.

<center>STEAM TRAPS.</center>

    A coil or calandria used for heating a pan or other vessel must
be provided with means for draining off the water that condenses

from the steam which is put into it for heating.   An open end is no good because the steam would just blow straight through and allow the pressure to drop inside the heating element, when the temperature would also drop.   It is necessary to keep up the pressure as well as to allow the water to escape.

The piece of plant which does this is called a steam trap, because it lets water escape but traps the steam.   There are many kinds of trap but most of those in use in the refinery work on the float principle.   The float trap is a small tank with a pipe entering it at the top and connected to the coil or calandria which it is desired to drain.   In the bottom of the trap is a valve which can be opened or closed by a float inside the trap.   When the float is low the valve is shut; when the float is high the valve is open.   A mixture of water and steam enters the trap by the top inlet.   As soon as enough water has collected to lift the float the valve is opened and the pressure inside the trap blows the water out until the water level is so low that the float closes the outlet valve.   In this way all the water that collects is got rid of but no steam can escape.

In some traps the float is heavier than water, in fact it would not float.   Actually the weight of a float does not matter; it can be counterbalanced.   The force acting on the float is quite independent of its weight; the force depends only on the volume of the float. The force is equal to the amount of liquid displaced.   Suppose we have a float whose volume is equal in capacity to one gallon.   The amount of water that this float displaces is one gallon, and one gallon of water weighs 10-lb.   The force that acts on a float this size is therefore 10-lb.   If the float is made of thin sheet copper it may weigh only three pounds.   In that case the force acting on it when it is submerged will be the weight of its own volume of water— 10-lb.—minus its own weight—3lb.   So that the net lift on the float will be 7-lb.   If we made our float the same size but made it of solid lead it would weigh 114-lb.   If we counterbalanced it with a weight of 111-lb. it would have a net weight of 3-lb. and the buoyancy effect would still be 10-lb. so that it would work just as well except that the whole thing would be nearly 20 times as heavy as the hollow float and would have to be much stronger and therefore less sensitive.   The great advantage of using a solid float is that it cannot puncture.   When a hollow float gets full of water its balance of forces is upset.   It still has the same buoyancy force acting on it but it needs counterbalancing.   The most reliable kind of float is a solid float made of light material so that the whole apparatus connected to it can be light and sensitive.   Some of our Arca traps have floats made of solid aluminium.   A float whose volume is such as to displace a gallon of water and made of solid aluminium weighs only 26-lb.

Water, like other things, expands as it gets hotter. Cold water weighs 10lb per gallon ; water at 158°C, the temperature of 70-lb steam, only weighs 9½lb. per gallon, while water at a temperature corresponding to a pressure of 650-lb. only weighs 8lb. per gallon. The float in a high pressure trap must be sufficiently buoyant to work in this light water.

A modification of the float principle which is used on some of our big pan trap tanks and on our pan flash tanks is a small tank suspended by a spring and connected to the main tank by a pipe from its top into the steam space of the tank and by another pipe from its bottom into the water space of the main tank. When the water level rises in the main tank it also rises in the little tank, which then weighs more and pulls on the spring supporting it. This pull is made to operate the supply to the hydraulic cylinder which works the outlet valve of the main tank. The steam pressure inside the tank blows the water out and the water level in the little tank falls. The suspension spring pulls the little tank back into its first position, which causes the supply to the hydraulic cylinder to be shut off and the main outlet valve shuts under the action of a counterweight.

Small traps for draining condensed water from steam pipes often work on the expansion principle. Inside the body of the trap is something, bellows or tube, which expands with heat much more than the body of the trap. The expanding member is so arranged that it closes the outlet valve of the trap when it is hot and opens the valve when it cools down. A trap of this type can only work at the end of a fairly long pipe which can dissipate the heat of the water. When the trap is full of water it cools down, and the expansion element contracts and opens the valve. This allows the water to be blown out. As soon as all the water has passed and steam enters the trap the expansion element expands and closes the outlet valve, because the steam cannot cool down in the trap, it can only condense.

EVAPORATION.

When we wish to thicken up a liquor or syrup we evaporate or boil off part of its water. When we use steam for this purpose what we are really doing is transferring the latent heat in the steam into latent heat in the vapour coming off the liquid we are boiling. In order to make the heat pass from the steam into the liquor there must be a temperature difference between them. This means that the pressure of the steam must always be greater than the pressure of the boiling liquid. The greater the temperature difference the faster will the heat pass, which means that the heating surface— that is the tubes in which the steam flows—can be smaller for a

higher temperature difference.　　Evaporation is discussed again in Chapter 10.

<center>CONDENSER LOSS—MULTIPLE EFFECT PRINCIPLE.</center>

When we use saturated steam at say 70-lb. pressure to boil a pan, we transfer the latent heat from the steam to the vapour coming off the liquor and this vapour carrying with it all the heat goes into the condenser where it gives up all its heat to the river water and the heat is lost in the river.　　Would it not be possible to use some of this heat over again ?　　Yes, provided other conditions allow it.　　If we use 70-lb. steam in the calandria of an evaporator or pan its temperature is 158°C.　　Let us lead the vapour that is boiled off the liquor into the calandria of another evaporator instead of into a condenser.　　Let the vapour from this vessel also go into the calandria of a third and so on until say the sixth vessel is connected to a condenser.　　If the vacuum in the sixth vessel is 28″ this corresponds to a boiling point of 38°C so that there is a temperature drop of 120°C over the whole plant.　　If the vessels are made the same size, the temperature drop will spread itself out evenly over the six vessels giving a drop of 20°C each, which is ample for economic heat transfer.　　Below is given a table showing the pressures and temperatures in the six vessels.　　Instead of the latent heat in our steam being used once only we have used it six times.　　It will be seen that the boiling temperatures in the first three vessels are very high and this is liable to cause the formation of colour and destruction of sugar.

	Evaporator Calandrias		*Boiling Liquids*	
Number of Vessel	Temp. °C	Press.	Temp. °C	Press.
1	158	70 lb sq. in.	138	35 lb sq. in.
2	138	35　　,,	118	12　　,,
3	118	12　　,,	98	2 in. vac.
4	98	2 in. vac.	78	17　　,,
5	78	17　　,,	58	24·5　,,
6	58	24·5　,,	38	28　　,,

Although by using an evaporator which has six " effects " it has been possible to use the latent heat in the steam six times this does not enable us to get quite six times the evaporation, because as the pressure goes down the latent heat goes up.　　Taking figures from the steam table we find :

Steam Pressure	Steam Temperature	Latent Heat
	°C	C.H.U.
70 lb	158	499
35 lb	138	514
12 lb	118	528
2 in.	98	541
17 in.	78	553
24·5 in.	58	564
28 in.	38	576

This means that one pound of 70-lb steam will only evaporate $\frac{499}{514}$ pounds of water at 35-lb pressure. And $\frac{499}{514}$ pounds of steam at 35-lb will only evaporate $\frac{499}{514} \times \frac{514}{528}$ pounds of water at 12-lb pressure and so on. Working this out we find that by using the steam, or rather the latent heat in it, six times, in a multiple effect evaporator having six bodies—called a sextuple effect evaporator—we could, starting with one pound of 70-lb. steam, evaporate 5·5 pounds of water before rejecting our latent heat, which is at so low a temperature as to be useless, to the condenser. This of course assumes that no heat is lost. In practice the most we should expect in such a plant would be about 4·75 pounds of water evaporated per pound of steam put into the first vessel.

Another complication arises when using multiple effect evaporators on sugar solutions because sugar solutions boil at higher temperatures than water. This is called " Boiling Point Elevation " and is discussed in greater detail in Chapters 10 and 11.

Why do we not seize such an obvious economy in our steam ? Because it would mean boiling liquors at very high temperatures and we should make colour, encourage inversion and destroy sugar. We want to boil our liquors and syrups at the lowest possible temperature. Very light liquors can be boiled in multiple effect and the cane and beet factories thicken up their juice in six or seven effect evaporators. There are no difficulties in the case of water. It has no boiling point elevation. It cannot invert or go brown. At Plaistow Wharf there is a quadruple effect Still making boiler feed water in which the water is boiling in three of the four bodies at temperatures above the melting point of solid sugar. More information on evaporation and particularly multiple effect evaporation will be found in Chapters 10 and 11.

Actually in our refineries we use all our steam at least twice and some of it seven times. Figure 25 is a diagram showing the ways in which the steam was used at Plaistow Wharf in 1938.

BOILERS
100

STILL 1st EFFECT
50 (1)

STILL 2nd EFFECT
50 (2)

STILL 3rd EFFECT
25 (3)

TURBINE
50 (1)

25 (2)

13 (3)

STILL 4th EFFECT
12 (4)

38 (2·33)

50 (2·75)

100 (1·87)

EVAPORATORS 1st EFFECT
5 (2·87)

PANS & COILS
95 (2·87)

EVAPORATORS 2nd EFFECT
5 (3·87)

100 (2·92)

92 (2·92)

SURFACE CONDENSERS
8 (3·92)

RIVER
100 (3·00)
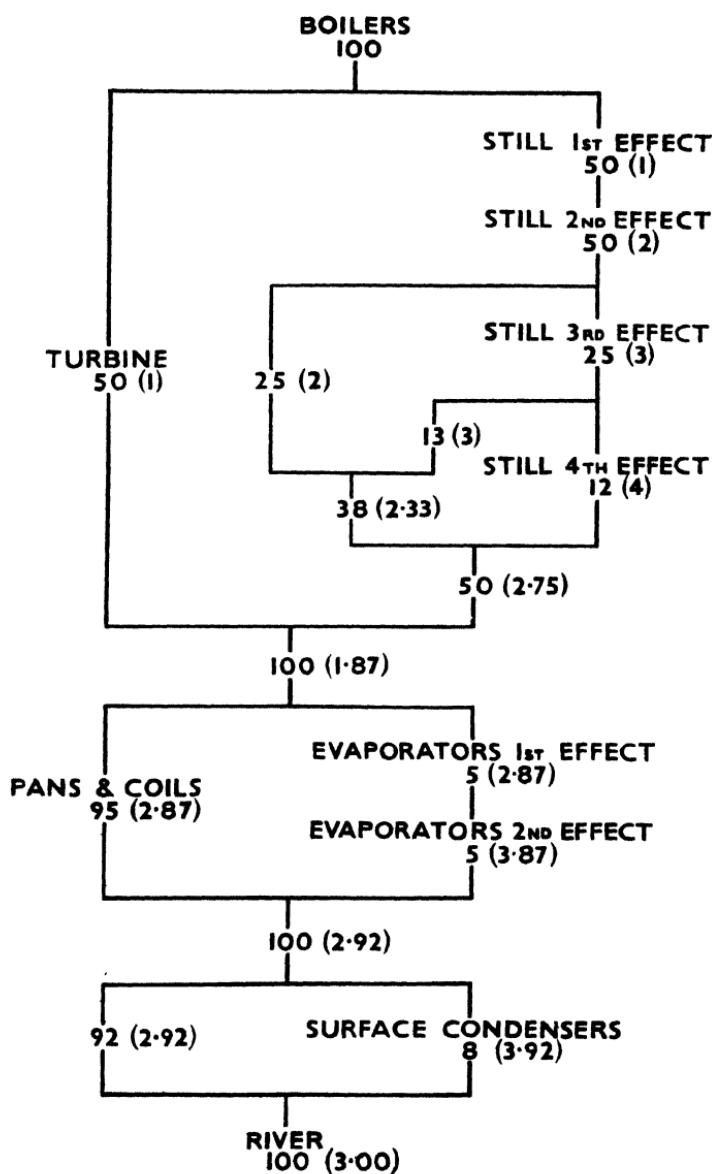
Fig. 25.
Plaistow Wharf Steam Path—1938.

The turbine has been included as one " use " which is not quite fair, because the turbine does not use latent heat. By taking an estimate of the proportion of steam which goes the different ways we see that all the steam was used just three times. The open figures represent the percentage of the total steam and the figures in brackets show the number of times the steam has been used.

POWER FROM STEAM.

An explanation of why all the plant is driven by electricity will be found in Chapter 7. It may be wondered perhaps why we do not raise our process steam at say 70-lb pressure and buy our electricity from the grid.

A big power station, for example Barking, raises steam at 650-lb pressure and 480°C. This steam contains 810 C.H.U. The water probably leaves the condenser at about 26°C so that some 784 units must have been put into the steam in the Barking boiler house. Now the Barking turbines exhaust into their condensers at about 29 inches of vacuum, corresponding to a steam temperature of 26°C, and steam at this temperature contains 609 heat units. So that Barking throws away $609 - 26 = 583$ out of every 784 units put into the steam. Owing to other considerations and by means of special methods of feed water heating by steam bled off at various points along the turbine it is possible to reduce the loss considerably and in practice Barking are much more efficient than the picture just drawn would indicate. The fact remains, however, that a big power station has to waste roughly two thirds of its heat whereas we do not need to waste any. Our costs for generating electricity should therefore be only one third of the cost of a condensing power station. In addition a very large part of a power company's costs consists of distribution costs, pylons, cables, transformers, etc. Now we have the same distribution costs whether we buy our electricity or whether we generate it ourselves, so that we should be able to make current at about one sixth of the cost of bought power. At week-ends, however, having no condenser in the power house and having no process demand for the turbine exhaust we have to exhaust to atmosphere if we wish to generate current. Steam at atmospheric pressure contains 639 C.H.U. and our 650-lb. steam contains 740 C.H.U. so that we should be wasting about six sevenths of our heat. Apart from this our turbine is inefficient at very light loads so we find it cheaper to buy our current at week-ends when the power company is very glad to sell cheaply.

Actually our power costs are nothing like as low as $\frac{1}{6}$ of Barking's, for many reasons. Our turbine is only $\frac{1}{16}$ of the size of

the four biggest turbines at Barking. It is therefore not nearly so efficient. We need a turbine driver, so does Barking, but our turbine driver costs 16 times as much as Barking's. Owing to our load fluctuations and week-end shut-downs, our repairs are higher. A big power company can buy coal considerably cheaper than we can.

THE STEAM TURBINE.

The reciprocating steam engine has almost disappeared as a serious competitor of the turbine for large power out-puts. The turbine is cheaper. It is more efficient. It occupies only about a quarter of the space for the same power output. It costs very little in repairs and is quite remarkably reliable. Sir Charles Parsons made the first practical turbine in 1884. In 1887 a Swedish engineer, de Laval, made another type of successful turbine. Most modern turbines combine the principles of both de Laval and Parsons.

The steam turbine is simply a number of small high speed windmills strung together on a shaft. The rotating part or rotor is a series of discs carrying curved blades on their edges. Steam is blown on to these blades through jets in the turbine casing. Between each rotating disc is a fixed ring of blades fitted in the casing to re-direct the steam at the correct angle on to the next row of rotating blades. The discs and rings are made gradually larger in diameter and the length of the blades is made increasingly long towards the exhaust end of the turbine in order to accommodate the increasing volume of the steam as it expands from its initial pressure down to the exhaust pressure. The more the steam is allowed to expand the greater is the amount of work that can be got out of it. The steam table on page 92 shows that the steam at the exhaust end of the Plaistow Wharf turbines occupies about eight times the volume that it required at the high pressure end. The steam at the low pressure end of the Barking turbines occupies over 600 times the space it occupied at the high pressure end. The steam turbine is very efficient at full load but as the load drops the steam con-sumption per unit of power output goes up. When the turbines at Plaistow are supplied with 650 lb. steam and exhaust into the 70-lb. process main they use about 29 lbs. of steam per unit of electricity generated when on full load ; but at quarter load they use about 45 lbs. of steam per unit. The exhaust pressure has a considerable effect on the steam consumption because the higher the exhaust pressure the less can the steam expand. With our high exhaust pressure we use about three times as much steam per unit of electricity that Barking does when exhausting into a high vacuum. So long as we can make all the electricity we want it does not matter whether we blow our steam through the turbine or through a reducing valve.

RADIATION LOSS.

Heat in anything at a high temperature tends to pass into the surrounding lower temperature things. All the hot plant and hot syrups in the refinery are trying to cool down and dissipate the heat that we have taken so much trouble to put there. The heat is lost in two ways. First by direct radiation. It is by direct radiation that the sun's heat reaches the earth. The second way is by what is called convection. The hot thing heats the surrounding air which rises and is replaced by cooler air which in turn is heated and rises. This convection is the chief way in which a hot pipe heats a room. Both these two ways of losing heat are generally lumped together and called radiation loss. In order to reduce the heat loss as far as possible we have to try to make the exposed surface cooler by preventing the heat passing through the walls of our pipes or plant.

LAGGING.

The lower the temperature of the exposed surface the smaller will the tendency be for heat to pass out into the surroundings. The outer exposed surface can only be supplied with heat from the hot inside part. So the first thing to do is to cover the hot thing with some material that lets heat pass through with great difficulty. Cork, asbestos, glass-wool and kieselguhr are best. We generally put on a layer about 2in. thick, though on very hot things or in very exposed places we sometimes make the "lagging," as the heat resisting material is called, as much as 4″ thick. As all good lagging materials are soft and easily damaged we always cover the "lagging" with steel sheeting. We calculate that it pays to put 2″ of steel-covered "lagging" on anything that is 40°C hotter than the surrounding air.

ALUMINIUM PAINT.

The amount of heat lost by true radiation depends not only on the temperature but on the surface of the hot thing. A polished surface radiates less heat than a dull surface. A light surface radiates less than a dark one. Dull black paint would be the worst we could use. Aluminium paint is the best. A careful test done at Plaistow Wharf in 1926 showed us that aluminium paint reduced radiation loss by 13%. That is why we use it throughout our refineries—not because it looks nice.

CHAPTER 6. STEAM BOILERS.

I took a kettle large and new,
Fit for the deed I had to do ;
My heart went hop, my heart went thump ;
I filled the kettle at the pump.

CARROLL—Through the Looking Glass—1872.

Boilers — Economisers — Air Preheaters — Superheaters — Watercooled
Furnace—Coal—Burning—CO_2—Smoke—Heating Power and Efficiency
—Measuring Boiler Efficiency—" From and At "—Boiler Fires—Draught
—Boiler Control—Ruths Steam Accumulator—Automatic Boiler Control—
Feed Water Regulation — Boiler Feed Water — Hardness —Water Treat-
ment—Distilled Water for Boiler Feed—De-aeration.

BOILERS.

The object of a boiler is to produce steam at a suitable pressure
and temperature and the steam must contain as much of the heat
from the burnt coal as possible.   The simplest kind of boiler is the
kettle or saucepan.   In such a boiler much of the heat is wasted by
passing round the sides and getting mixed with the cold surrounding
air.   The most obvious improvement to a boiler was to close in the
fire and ensure that all the heat goes round or through the boiler.

The Lancashire boiler is a long cylindrical tank with two large
tubes running lengthways through it.   The fires occupy one end of
these tubes and all the hot gases from the fires have to pass along
the full length of these tubes or "flues" completely surrounded by
boiler.   This was a great improvement on the open fire, but the
gases still left the boiler very hot even though in later designs of
Lancashire boiler the gases, after leaving the flue tubes, were led up
one side and down the other side of the outside shell of the boiler
drum.   Much of the heat still went up the chimney.   The actual
metal surface of a Lancashire boiler that is exposed to the hot gases
is comparatively small, consequently a great many boilers were
needed if a lot of steam was wanted.   It is not practical to make a
very large Lancashire boiler even for moderate pressure as the shell
would have to be so thick.

The ·need for larger boilers and higher pressures caused the
rapid development of the water-tube boiler, in which the fire is
enclosed in a furnace and the gases pass banks of tubes which

contain the water. Owing to their small diameter these tubes can be quite thin even for very high pressures. The tubes lead into two or more comparatively small drums. In the upper drums the steam escapes from the water. The lower drum serves merely as a means of connecting the tubes together and enables the lower part of the tubes to be inspected and permits the through passage of a tube-cleaning tool. As none of these drums are exposed to the corrosive action of the fire they need only be strong enough to stand pressure, and as they are small each can be forged from a single ingot into a jointless cylinder.

ECONOMISERS.

The higher the pressure the higher is the boiling point of water and the hotter must be the gases passing the last row of boiler tubes. It is therefore impossible to take much of the heat out of the gases in the boiler itself if the pressure is high. But the feed water going into the boiler is comparatively cool, possibly well below 100°C. The feed water is made to pass, on its way into the boiler, through a bank of tubes at the back of the boiler which are in the flue leading the gases from the boiler to the chimney. This bank of tubes, called an "economiser" because it economises heat, must not be made too large for two reasons. It is undesirable and sometimes dangerous to boil water in the economiser and it is undesirable to cool the gases down to such an extent that acids from the burnt coal may condense on the tubes and corrode them.

AIR PREHEATERS.

When coal is burnt it requires about 16 times its own weight of air to burn it. All this air must be heated up to flame temperature—a fact which is not generally appreciated until thought about. Therefore if there is any way in which we can heat the air before it goes into the the furnace we shall make more coal heat available for boiling. An air-preheater is a plant for taking the waste heat out of the flue gases after they have left the economiser and transferring it to the air on its way to the furnace. There are many kinds of air-preheater, but only the type used by T & L need be described. This is the heater designed by a Swede called Ljungström. It consists of a large shallow drum packed with thin corrugated metal plates. This forms a multitude of honeycomb-like passages with metal walls. The drum is made to revolve slowly. Through one side of the drum the flue gases are drawn on their way to the chimney. At the opposite side of the drum the air on its way to the furnace is blown through by the forced draught fan. The flue gases heat up the metal plates with which the drum is packed. The drum rotates carrying the hot metal passages round to the opposite side where the cold air is blown through. The air takes the heat

out of the metal and is consequently heated up and the cooled metal plates go round until they are again heated up by the gases. As the air heater is under no pressure and only has to be strong enough to hold itself together it does not greatly matter how much the flue gases are cooled and it is possible to cool the gases before discharging them to the chimney more than by means of an economiser alone.

By means of the boiler tubes, the economiser tubes and the air-preheater the flue gases which reached the first row of boiler tubes at about 1250°C are reduced to about 130°C before entering the chimney.

SUPERHEATERS.

As has already been explained it is mechanically dangerous to allow the steam in a turbine to contain drops of water and in order to ensure that there is not too much water in the engine or turbine at exhaust point, the steam is superheated. Another most important reason for superheating is that an engine or turbine cannot use the latent heat in the steam whereas it can use the superheat. So that the more heat, in the form of superheat, that each pound of steam contains the more efficient will the engine be that is using the steam. For example, let us assume that an engine is to exhaust at 10 lb. pressure. The heat in 10-lb. saturated steam is 645 C.H.U. If the engine is supplied with saturated steam at 200-lb., such steam has 666 C.H.U. so that the engine has only got 21 C.H.U. that it can turn into work for every 645 units rejected in the exhaust. Now suppose that instead of 200-lb. saturated steam which has a temperature of 198°C we superheat the steam up to 300°C then each pound of steam will now have 726 C.H.U. so that there are now 81 units of heat available to be turned into work. This clearly is an enormous advance. Of course it is not quite as easy as this. Steam at 300°C is pretty hot and if used in a reciprocating engine would cause great trouble with the proper lubrication of the cylinder. But turbines can use hotter steam than this. One of the American power stations in Detroit uses steam at 540°C which means that in the dark the high pressure end of the turbine can be seen glowing !

The superheater of a boiler is a bank of tubes which is connected at one end with the outlet from the boiler steam drum and at the other end with the boiler stop-valve. The bank of superheater tubes must be placed in the right part of the boiler to get the correct amount of superheat. If the superheater were placed between the boiler tubes and the economiser the gases there would probably not have sufficient temperature to heat the steam sufficiently. If the superheater were placed in the furnace in front of the boiler tubes. the superheater tubes might be heated to such a high temperature as

to soften and burst.   The superheater is generally placed about one third of the way through the boiler.

WATER COOLED FURNACE.

When powdered coal was first tried for firing boilers it was found necessary to use a very large, high furnace in order to ensure that each particle of coal was burnt before reaching the comparatively cool boiler tubes.   These powdered coal boilers were found to be very efficient—that is to say the boilers were able to absorb a very large amount of the heat in the coal. This efficiency was at first thought to be due to the powdered coal whereas most of it was due to the large furnace.   In all our old boilers the furnace is so small that the flame touches the tubes.   As the tubes are comparatively cold the flame is put out prematurely, smoke is formed and soot deposits on the tubes in " birds' nests."   Smoke and soot are unburnt matter and are wasteful.   Soot on the tubes prevents the heat getting to the metal of the tubes.   The large furnace ensures that everything is burnt before it reaches the tubes.   Good efficient burning only takes place if the furnace walls are white hot.   As boilers got bigger and bigger it was found that there was so much heat in the furnace that the firebrick walls melted.   This trouble was overcome by watercooling the furnace walls.   The Bailey water-cooled walls in the modern T. & L. boilers consist of a single row of closely spaced tubes encased in cast iron blocks.   These blocks are recessed on the face which forms the furnace wall and the recesses are filled with fireclay.   The fireclay gets white hot and promotes good burning while the cast iron transfers a lot of the heat to the wall tubes and prevents the wall from overheating.   By using the furnace walls as part of the boiler the rest of the boiler can be made smaller.

COAL.

Coal is a buried forest millions of years old.   It is just wood and vegetation compressed by the weight of thousands of tons of soil and rock which have been washed down on it by prehistoric rivers, glaciers and floods.   Coal contains about 10% water, about 5% of unburnable ash and the rest is stuff that will burn, chiefly in the form of carbon and hydrogen.

BURNING.

When coal is heated the first thing that happens is that water vapour and marsh gas, or fire damp, are given off.   When heated still more other gases are given off and oily substances are boiled off. With more heating the coal is softened into a sticky mass and the tar is boiled off.   When all the tar has been boiled off the coa

becomes a dry porous mass called coke. With further heating and an adequate supply of air the "fixed" carbon in the coke is burnt leaving only the unburnable ash. Once coal can be "lighted," that is heated sufficiently, it will heat itself up and go through all these stages, each stage supplying the necessary heat to produce the next stage in each piece of coal. There are therefore two distinct main stages in the burning of coal. The first is the flame part where the "volatile" matters, the gases, oils and tars are driven off and which burn as long yellow flames. The second stage is the burning of the fixed carbon in the coke, and the burning coke becomes a glowing mass with very short pale flames. These flames are the burning of the gas carbon monoxide. When carbon burns completely it burns to carbon dioxide or CO_2. If there is a lack of oxygen it will burn to the gas carbon monoxide or CO. When oxygen reaches the gas carbon monoxide it combines to form carbon dioxide the combination being performed by burning with a short pale flame. As it is impossible to ensure that each bit of coal gets its exact amount of air some of the carbon in some of the coal is first burnt to carbon monoxide, but almost immediately it meets some "spare" air with which it burns to carbon dioxide.

CO_2—SMOKE.

Air consists of a mixture of gases of which nitrogen is 78% and oxygen is 21% The remaining 1% is water vapour, carbon dioxide, and a number of rare gases. As far as burning is concerned the oxygen is the only useful part of air. The nitrogen is just an adulterant which has to be heated up but which takes no useful part. When coal is burnt the heat is produced by the oxygen combining with the carbon and hydrogen. When carbon burns completely it burns to carbon dioxide or CO_2. When hydrogen burns completely it burns to water vapour or H_2O. If the exact theoretical amount of air were supplied to the coal during the burning, the amount of CO_2 in the flue gas leaving the boiler would be 18%. This is quite impossible in practice as it would mean supplying each little bit of coal with its exact quantity of air for the particular stage of burning that it had reached. In order to ensure complete combustion it is necessary to supply too much air to the furnace in general in order that particular parts can always be sure of an adequate supply, and experience has shown that 14% of CO_2 in the flue gas is the best for efficient working. If too much air is added the heat is just wasted. The excess air can do no good in the burning, it cools down the furnace and it goes up the chimney with heat in it. We cannot cool the chimney gases down much more than to about 130°C and the greater the quantity of gas that goes up the chimney for a given amount of coal burnt, the more heat is lost. On our old boilers with furnaces too small

and no control of the distribution of the air in the grate we are seldom able to cut the air supply down to such an amount as to give more than 10 to 11% of CO_2 in the flue gas. In modern boilers not only is the furnace big enough to ensure complete combustion but the amount of air to each part of the fire can be controlled. As combustion is almost perfect on the modern boiler very little smoke is made. But with small combustion chambers and haphazard air supply as on our older boilers it is impossible to burn up all the smoke unless far too much air is supplied to the grate and very wasteful burning is the result.

The heat that we lose in a boiler is principally that which goes up the chimney. Now if air leaks into the flues at the back of the boiler and into the economiser we may be putting a lot of unnecessary heat up the chimney. This can be checked by measuring the CO_2 at the chimney as well as at the back of the boiler furnace. If the boiler shows 14% of CO_2 and the base of the chimney shows 7% it clearly means that we are putting twice as much gas up the chimney as we are making in the furnace. Now all the gas going up the chimney will be at the same temperature because our air-preheater can only reduce the temperature to a certain amount so it follows that we shall be wasting up the chimney just twice the heat we need to.

HEATING–POWER AND EFFICIENCY.

The best coal that we buy contains about 7000 C.H.U. per pound. That is to say that this is the figure we should be able to get from burning 1-lb. of coal if we were able to burn it perfectly. It has been explained previously that we need to add 539 C.H.U. of latent heat to a pound of water at 100°C in order to convert it all into steam. So that if we had a perfect boiler full of water at 100°C and we burnt our pound of coal in a perfect furnace using the exactly right amount of air we should be able to evaporate $\frac{7000}{539}$ or 13-lbs. of water.

In practice however we cannot take all the heat out of the flue gas and the boiler loses heat by radiation and we take out our clinkers while they are still red hot and we have to use too much air for perfect burning so that the most efficient large boiler can only use about 85% of the heat in the coal. Our modern Stirling boilers have an efficiency of 84 to 85% but the old Babcock boilers with their maze of flues and small furnaces only have an efficiency of 68%.

MEASURING BOILER EFFICIENCY.

In order to find the efficiency of a boiler all that need be done is to measure the amount of steam generated in, say, a shift; weigh

the amount of coal burnt in the same time and find the heating power of the coal. For example, suppose that the amount of coal used by one of the big boilers at Plaistow Wharf in one shift was 52 tons and that the steam meter shows that 1,000,000 pounds of steam have been made. Then the actual evaporation that has been done by each pound of coal was $\frac{1,000,000}{52 \times 2240}$ or 8·58. Now the total heat in 650-lb. steam at 370°C is 748 C.H.U. But the feed water entered the economiser at say 80°C. Therefore 668 C.H.U. have been added to each pound of steam. We still need to know how much heat each pound of coal contained. A sample of coal is taken and powdered. A weighed amount of the coal powder is placed in a strong metal " bomb " which is afterwards filled with oxygen. The bomb is then immersed in a vessel containing a known amount of cold water. The whole thing is then left for a time so that the water will come to the same temperature as the bomb. The coal dust is then exploded—that is made to burn instantaneously—by an electric spark. The bomb is strong enough not to burst and the heat of the explosion is passed through the metal of the bomb to the water in the vessel. The rise in temperature of the water is measured and as the weights of coal dust and water are known the heating power of the coal can be worked out. Suppose the bomb shows that the coal contained 6800 C.H.U. per pound, then the amount of water that a perfect boiler would have evaporated would have been $\frac{6800}{668}$ or 10·18-lbs. of water per lb. of coal. As we only obtained 8·58-lbs. the boiler efficiency must have been $\frac{8·58 \times 100}{10·18}$ or 83·3% efficiency over the shift.

<center>"FROM AND AT."</center>

Boiler engineers, for some mysterious reason, seldom speak of the relative efficiency of boilers. When comparing the performance of boilers on different steam pressures and temperatures it is usual to express the boiler performance as if it had evaporated steam " from " water at 100°C and turned it into steam " at " 100°C. The actual evaporation is no guide for comparison of performance (nor is the " from and at " figure unless the coal is the same in each case).

Suppose that our old Lancashire boilers are generating saturated steam at 45-lb. Each pound of this steam contains 655 C.H.U. and as the feed water was at say 80°C each pound of steam had 575 C.H.U. put into it. Now the heat needed to make steam from and at 100°C is 539 C.H.U. so that one pound of 45-lb pressure Lancashire steam is equivalent to $\frac{575}{539}$ or 1·065 pounds of " from and at " steam. Our old Babcock boilers generate steam at 240-lb. and 250°C. This steam contains 695 C.H.U. and if the feed water was at 80°C then one pound of this steam is equal to 1·14 pounds of " from and at " steam. Similarly one pound of 650-lb. steam from

the high pressure boilers is the equivalent of 1·24 pounds of " from and at " steam.

BOILER FIRES.

It would be quite impossible to fire a big modern boiler by hand. No man could throw six tons of coal an hour over the huge grate area. The opening of the furnace doors would upset all the accurate proportioning of the air. The raking out of ashes would be even worse. As there are distinct stages in the burning of coal it is very desirable to keep these separate and to give each its proper air supply. Hand firing must muddle up the burning stages. By feeding the fire mechanically the burning stages can be kept separate and supplied with their correct air and the ashes can be removed without allowing undesired air to enter the furnace. The simplest and most effective way to do this is to make the grate a slowly moving chain. The coal is fed on to one end of the chain which slowly traverses the furnace and discharges the ashes at the far end. There are two ways of regulating the amount of coal burnt. By the thickness of the coal layer on the grate or by the speed at which the grate moves. The thickness of the coal on the grate is generally fixed by the type of coal being burnt. The soft, easy burning coals such as we use burn well on a thick bed, while the hard coals like Welsh coal or anthracite burn better with thin coal beds. Once the best thickness has been found for the particular coal in use the amount burnt depends on the speed of the grate.

DRAUGHT.

Each pound of coal requires about 16 pounds of air to burn it completely, but as has already been explained in this chapter we cannot rely on perfect burning everywhere so that in practice it is necessary to supply the grate with about 20 pounds of air for each pound of coal. Each square foot of grate can burn about 30 pounds of coal per hour. Therefore each square foot of grate must be supplied with about 5 hundredweights of air per hour. The weight of preheated air is such that, if the air spaces between the links of the chain grates occupy about one twelfth of the grate surface the air will have to pass through the grate at 30 miles an hour. In older boilers where the air and flue gases did not have to pass through air preheaters natural chimney draught was sufficient. But with the extra resistance of air heaters it is necessary to force or draw the air through the grate. A fan that draws the gases through all the boiler accessories and discharges into the chimney is called an induced draught fan. Such a fan can draw the air through the grate and draw the air first through the air preheater. A fan which blows the air into the grate is called a forced draught fan. Such a fan can blow the air through the preheater then through the

grate and finally blow the gases through the preheater into the chimney. Single fans such as those just mentioned have to be very large and powerful and the air pressures or suction on the gases have to be very high with consequent risk of leakage, so that almost all large boilers have both forced and induced draught fans. The forced draught fans blow the air through the preheater into the bottom of the grate and the induced draught fans draw the gases from above the grate through the boiler tubes, economiser and air preheater and discharge them into the chimney. The pressure in the furnace is usually kept at atmospheric pressure so that a door can be opened for inspection purposes without gases being blown out or air being drawn in. Much less power is used by the two fans together than would be used by one either forced or induced fan.

Natural draught of course helps the fans to a large extent. Natural draught in a chimney is caused by the column of air in the chimney being hotter and therefore lighter than the air outside. So that the weight of the air pressing on the bottom of the grate is much more than the weight of the hot flue gases pressing on the top of the grate with the result that the air is forced through the grate. The higher the chimney the greater will the pressure difference be on either side of the grate.

BOILER CONTROL.

In a sugar refinery the steam demand is very erratic. One big fine sugar pan when first put on uses about one quarter of the total steam and when the pan is shut down the steam cut off may be about one eighth of the total. These fluctuations which may occur several times an hour are very difficult to meet. In order to raise more steam the grate speed must be increased and the induced draught fan must be speeded up to draw the necessary extra air through the fire. The forced draught fan must also be accelerated to balance the pressure in the furnace. It is very difficult to do all this quickly and accurately by hand. If the fireman tries to make all these adjustments for very little change in load he may easily overshoot the mark and make too much steam which will just blow to waste through the safety valve or make too little when the pressure will drop. He is also tempted to wait and see whether the pressure change is just temporary. If it is not, he will be too late with his adjustments. There are two methods by which this boiler control can be made easier, either by means of an automatic control system or by the installation of a steam accumulator.

THE RUTHS STEAM ACCUMULATOR.

Variations in load can only be taken easily on a modern sensitive boiler and even then the variations upset the boiler, which

will work much better on a steady load.   Old boilers only work
efficiently at steady load.   At Plaistow Wharf another reason drove
us to use a steam accumulator.   Our boiler plant was too small and
unless we had some way whereby the boilers could be kept on full
load all the time, the output of the refinery could not have been kept
up.

The Ruths accumulator is a piece of plant which will receive
surplus steam and store it when the process demand is light, and
will give out the stored steam when the process demand is more
than the boiler can meet.   The accumulator consists of a very large
drum two thirds full of water.   The steam inlet is a long pipe, below
the water level, carrying a number of nozzles or blowers.   The
steam outlet is an open pipe in the steam space at the top of the
vessel.   It has already been explained that the boiling point of water
rises with the pressure, and that steam will flash off water that is
reduced in pressure so that its temperature is above the corresponding
boiling point.   The action of the accumulator is as follows : When
the steam pressure in the process main rises above normal this
pressure opens a valve which admits steam from the boiler main
into the accumulator through the nozzles.   This steam condenses in
and gives up its heat to the water in the vessel and consequently the
water rises in temperature and pressure.   When the process pressure
drops this drop opens the surplus valve from the boilers into the
process main.   If the process main still loses pressure the accumu-
lator discharge valve opens and releases some of the pressure in the
vessel.   At once some of the high temperature water flashes off
into steam.   In this way, due to a drop in pressure, the accumulator
gives up its store of heat in the form of flash steam.   Our
accumulators have a storage capacity of about 70,000-lbs. of steam.

AUTOMATIC BOILER CONTROL.

Automatic control on high pressure boilers can be very sensitive.
It will start making an adjustment before the pressure gauge shows
a noticeable change.   It is not necessary to describe the control in
detail.   Briefly it works like this.   Every 15 seconds the boiler
pressure is measured.   If the pressure has gone down or up the
grate speed and induced draught are adjusted.   The measuring
mechanism is such that the amount of correction given to the fire is
proportional to the amount by which the pressure has changed in
the 15-second interval.   The forced draught fan follows the induced
draught adjustment in such a way as to keep the furnace pressure
balanced at atmospheric pressure.   The automatic control is much
more sensitive than a man and keeps the boiler pressure much more
steady than can be done with hand operation.

FEED WATER REGULATION.

It is essential that the boiler tubes exposed to the hot gases should always be kept full of water. If the water level were to fall the top part of the tube would contain only steam and that part of the tube might get overheated, soften and burst. So long as a tube is clean and full of water it can never get very much hotter than the water boiling point at the pressure in use, however hot the fire. Experiments have been made which show that the fire side of a clean boiler tube is only from $20°C$ to $40°C$ hotter than the water side. It is equally important that the boiler should not get too much water in it lest water might be carried over with the steam into the turbine or engine when great damage might be done. A water gauge is provided to show those in charge of the boiler the level of the water. The water gauge is just a stout glass tube connected at either end with the boiler. It is attached at such a level that the water is half way up it when the boiler contains the right amount. Cocks are provided above and below the glass tube so that the glass tube can be renewed in the event of breakage without having to shut the boiler down. With very high pressures it might be very difficult to reach these cocks in the event of the glass tube breaking without risk of being burnt, so a little automatic valve is provided top and bottom beside each cock which consists of a ball lying in a recess. If the glass breaks the rush of escaping steam carries the ball along to a narrower part of the fitting and closes the opening.

In big modern boilers the water level is so high above the firing floor, from which the boiler is controlled, that the level in the gauge glasses cannot be seen. An image of the gauge glass is reflected by means of periscope mirrors on to a screen on the firing floor.

Automatic feed water regulators are now reliable and are able to keep the water level fairly steady. The Copes regulator used by T. & L. is a long unlagged metal tube not quite horizontal but inclined slightly. It is connected at each end to the boiler in such a way that its middle point is level with the level at which the water is to be kept. The top end of the tube will therefore be in communication with the steam space while the bottom end will be attached to the water space. As the tube is nearly horizontal any variation in the boiler water level will show a very magnified movement in the inclined tube. The water in the tube has no circulation and will soon get cool by radiating to the surroundings. It will be much cooler than the steam above it. The steam can condense but it cannot cool in temperature. The higher the water level in the boiler the longer will be the cool part of the regulator tube, because it will contain chiefly cooled water. On the other hand, if the water level drops, the tube will contain much more hot steam. When the

tube is hot it expands and when it cools it contracts.   It is so arranged that, by means of suitable links, its expansion opens the feed valve and its contraction closes the valve.

BOILER FEED WATER.

We are apt to think of water as a bright pure liquid.   Actually, Metropolitan Board water is just a rather dilute solution of certain salts.   When water is boiled a chemical change takes place in some of these salts, which are thereby made insoluble.   Other salts do not undergo any change but are also thrown out when sufficient water has been evaporated to produce a supersaturated solution (see page 41).   These solids that are thrown out of the water on to the hot metal get baked hard on to the metal surface and prevent the heat getting through to the water.   Everyone knows how a kettle gets furred or scaled up by the solids thrown out of the water.   Everyone also knows how long it takes and what a lot of heat is wasted in bringing a furred kettle to the boil.   In a high pressure boiler there is another serious effect.   If the heat cannot get through the tube to the water the tube may get red hot and bulge or even burst.

HARDNESS.

It is possible by suitable chemical treatment to prevent these solids being thrown out in the boiler.   We cannot take them all out of the water but we can readily change their composition so as to improve their behaviour.   The two principal salts in London water are calcium bicarbonate and calcium sulphate.   These two salts are the cause of the " hardness " of the water, so called because of the " hard " feeling when trying to get a soap lather with such water. This hard feeling is very different from the feeling given with soap and a " soft " water such as Liverpool water.   The hardness due to the calcium bicarbonate is called " temporary " hardness because if the water is boiled the bicarbonate is split up into carbonate and CO_2.   If the carbonate of calcium, or chalk, is allowed to settle and the clear water run off, the water will have no temporary hardness in it.   It is temporary hardness that furs up the domestic kettle. The hardness due to the calcium sulphate, on the other hand, cannot be removed by boiling and is called " permanent " hardness.   When water having permanent hardness is evaporated to give steam the hardness gets more and more as the concentration increases until the water is supersaturated, when the calcium sulphate is thrown out. This occurs at a comparatively low concentration as calcium sulphate is only sparingly soluble in water.

WATER TREATMENT.

It would be a waste of heat and not at all practical to remove

the temporary hardness by boiling the water outside the boiler. Both temporary and permanent hardness can be removed by simple chemical means. In the Porter-Clark or Lime-Soda process this is done very effectively. (The writer does not know who Porter was, but Thomas Clark was a professor of chemistry in Aberdeen and invented this water-softening process 100 years ago.)

If milk of lime is added to a water which has temporary hardness, the lime combines with the CO_2 in the bicarbonate to form carbonate of lime or chalk. The CO_2 having left the bicarbonate leaves carbonate or chalk behind. The result is that instead of added lime and bicarbonate in the water, we have two lots of chalk which are not soluble in water and are thrown out as a precipitate when they can be removed by settling or filtration or, as we do, by both.

If sodium carbonate—soda ash—is added to water which has permanent hardness, that is calcium sulphate, in it, the sodium and the calcium change places and sodium sulphate and calcium carbonate are formed. Calcium carbonate is chalk and will settle or filter out. Sodium sulphate is very readily soluble in water and water containing it can be very highly concentrated before there is any chance of its being thrown out of solution. At about $2°$ Bx long, before such a concentration is reached, some of the water is blown out of the boiler down the drain to prevent the concentration getting too high.

There are other impurities in water and there are other refinements in water treatment. But except for two matters, we do not need to consider them. A serious condition in a high pressure boiler has to be guarded against. This is called " caustic embrittlement." It is an action on the steel of the boiler drum causing small cracks to grow from rivet holes or sharp corners. It only occurs if an excess of sodium carbonate has been added to the water so that the amounts of sodium carbonate and sodium sulphate are present in about equal quantities. For good softening it is usually necessary to add rather too much sodium carbonate. In order therefore to keep the proportion of sulphate to carbonate correct it may be necessary to add some sodium sulphate.

DISTILLED WATER FOR BOILER FEED.

Distilled water is by far the best feed for a boiler as there are no dissolved solids to deposit on the heating surface. In a sugar refinery there is plenty of distilled water from pan and evaporator heating surfaces, in fact almost all the steam used should condense into available distilled water. All of this water, however, may be contaminated with sugar, when we call it " sweet." At high temperatures sugar will break up into acids which would attack the

steel of the boiler. When using distilled water from the process we have continually to test it for " sweet." If any sweet water is used as boiler feed we add a little alkali to neutralise the acids which are formed by the breakdown of the sugar.

DE-AERATION.

Air in small quantities dissolves very easily in water provided it is below its boiling point. Both oxygen and carbon dioxide attack the steel of boilers and economisers at high temperatures. It is most important to remove these gases before the water enters the boiler. The piece of plant which removes this dissolved gas is called a de-aerator and consists of a small vessel into which the water is sprayed. The vessel is connected to an ejector or vacuum pump which creates a slight vacuum so that the pressure in the vessel is lower than the pressure corresponding to the boiling point of the water for its particular temperature. For example water at 80°C boils at 16″ of vacuum and a suitable pressure for the de-aeration of water at that temperature would probably be about 18″ of vacuum. Water at 100°C which boils at atmospheric pressure could be de-aerated at 2″ of vacuum. When the water is sprayed into the vacuum some of it flashes off almost instantaneously and with this flash go the gases. The exhaust steam from the ejectors together with the flash from the de-aerated water is used either in heat exchangers or blowers for heating water, where a little air will do no damage.

CHAPTER 7. ELECTRICITY—PRODUCTION.

And vivid lightnings flash from pole to pole.

SCOTT—On a Thunderstorm—1783.

Convenience of Electricity—What is Electricity ?—Sources of Electricity—Magnetism — Conductors and Insulators — Pressure and Quantity —Volts and Amperes — Ohm's Law — Power — Watts — Kilowatts — Board of Trade Units—Heating Effect of Electricity—The Generation of Electricity—Simple Dynamo —Alternating Current—A . C . — Frequency—Phases — Alternators and Generators—Direct Current—D . C .

The main text of this chapter contains no reference to the illustrations, which carry their own explanations, printed in italics.

CONVENIENCE OF ELECTRICITY.

Just as steam is an ideal medium for bringing heat to any part of the refinery, so is electricity an ideal method of distributing power. Up to about 1910 all the plant in the whole refinery was driven by steam engines. In the 1909 edition of " Sugar " by Newlands, opposite page 568 is a drawing of Plaistow Wharf as it was built in 1882. It is difficult for those brought up in an electrical age to appreciate just what this was like. Steam engines were wasteful, hot and dirty. A small steam engine is very inefficient and wastes much of the steam that comes to it. The valves and glands generally leaked. Oil was thrown about. A great tangle of steam pipes, all losing heat by radiation, wandered all over the factory. Another and larger tangle collected the exhaust steam from all these engines and brought it back to the pans. A steam engine has a lot of mechanism which easily goes wrong and which requires a lot of attention and lubrication. It requires quite a number of minutes to start even the smallest steam engine from cold. Water must be drained out and the cylinders must be warmed up before the engine can be put on load. The biggest electric motor can be started in about 20 seconds, smaller ones in 5 seconds or less, and all, regardless of size, can take full load right away and run with little or no attention. An electric motor has just one moving part in two bearings. All it needs is to be kept reasonably clean and dry and to have a little grease added to the bearings occasionally. The reliability of the electric motor is quite remarkable. At Plaistow

Wharf there is an old motor on the wharf which drives the raw sugar traveller under the silos. It runs for 140 hours per week. It has been running in the open air for 30 years without ever having given any trouble at all. Centrifugal machine motors may appear to be troublesome, but they are really very reliable considering the work they do. Many machine motors run for a year or two without trouble, which means that they may have done over 100,000 full load starts. Not a bad record.

Apart from reliability an electric motor can be put anywhere. It occupies less than a quarter of the space that the corresponding steam engine needs. When designed for the purpose it is just as happy in the open air as in a glass case. The automatic protection that can be given to it is also of great value. Overload cut-outs and fuses protect not only the motor but the plant it is driving. The ability to stop a motor in an emergency by a push button a long way from the motor is another advantage.

In addition to its advantages for power purposes, electricity is a clean, convenient, safe and bright source of light.

WHAT IS ELECTRICITY?

No scientist has yet been able to tell us what electricity is. We know how to produce it, what it does, and how to use it. It is probably a flow of incredibly tiny particles called electrons, but no microscope or other instrument has enabled us to see any motion. A wire looks just the same whether a current is flowing along it or not. The only visible effect of electricity is when the heating effect is sufficient to make the carrier of the current red or white hot.

SOURCES OF ELECTRICITY.

Electricity can be produced in many ways. If an ebonite fountain pen is rubbed on a dry coat sleeve the pen will pick up little scraps of paper or pieces of dust. The pen has been "charged" with electricity and attracts the uncharged pieces of matter. After a few seconds the little bits of paper will drop off because the electrical charge has flowed into the paper and both pen and paper are equally charged and have no mutual attraction.

Many girls and some men will have noticed that in very dry weather a comb will crackle when combing the hair and in the dark sparks can be seen. The rubbing of the hair with the ebonite comb has charged the comb with one kind of electrical charge called a negative charge while the hair has got a positive charge. The positive charge flows towards the negative charge by the spark and the charges then cancel one another out. It is these sparks which constitute the danger of using a celluloid comb.

The production of electrical charges by rubbing was discovered at least 2,500 years ago in the case of amber, which when rubbed gets charged very easily. The Greek name for amber is "electron," hence the name electricity. This 'electricity which appears as charges and disappears as discharges is not the kind of electricity that we use in our homes and factories. This "static" electricity, as it is called because it is normally stationary as a charge, is the electricity of a thunderstorm which is formed by upward wind currents breaking-up rain drops. This causes the broken drops to have one charge and the air to have another. It should be particularly noticed that static electricity exists in things that we shall presently see are the things through which ordinary current electricity will not flow.

Current electricity is non-existent except when flowing and is the electricity which we use for power, light or telephones. It can be produced in three ways. By chemical means in a cell or battery. If a rod of copper and a rod of zinc are immersed in a jar containing dilute sulphuric acid a current of electricity will flow through a wire joining the two rods. Cells are used to produce the small currents used for bells, telephones and some radio purposes.

If certain metals are joined together very perfectly and the junction is heated, a current will flow through a wire joining the un-jointed ends of the metals. This source of electricity is only used now as a means of measuring high temperatures (see page 36).

By far the most important source of electricity is its production by moving a wire near a magnet. This is the principle upon which the dynamo or generator works and was discovered by Michael Faraday—the father of electrical engineering—in 1831. Faraday was a blacksmith's son and he started work as a newsboy at the age of 7. At 13 he was apprenticed to a bookbinder and he is said to have read every book he bound. At 21 he was Sir Humphrey Davy's assistant. Davy was the inventor of the miners' safety lamp and did a lot of electrical research.

MAGNETISM.

Magnetism is just as difficult to explain as electricity. If current electricity is looked upon as a flow of invisible electrons, magnetism can be looked upon as a state of strain or tension in the electrons making up the magnet and the "magnetic field," as the space around the magnet is called. Magnetism exists naturally in the earth, which is a large weak magnet. Magnetism also exists naturally in a certain kind of iron ore which was discovered in pre-historic times near the town of Magnesia in Asia Minor—hence the name magnet. This iron ore attracted iron particles, and a suitably

long-shaped piece if hung up so as to be able to swing freely would always point north and south.   So this ore was called Lodestone or Guiding stone for many centuries.   The magnetic compass is believed to have been in use by the Chinese 3,000 years ago.   Nowadays Lodestone is merely an historical curiosity as far as magnetism is concerned.   It is a good ore for making into iron.

Only three metals have magnetic properties—iron, nickel and cobalt.   Of these iron is by far the most important.

A magnet is produced if a piece of iron has wound round it a coil of wire through which an electric current is passed.   If the iron is soft and pure the magnetism ceases as soon as the electric current stops flowing.   The amount of magnetism, or as it is called, the strength of the " magnetic field," is proportional to the number of turns of wire in the coil and on the amount of current flowing. After a certain amount of magnetism has been produced no increase in the current or in the number of turns in the coil will make any difference because the iron has become " saturated."   Certain steels which have been magnetised electrically will retain their magnetism almost indefinitely.   They are called " permanent " magnets and their use is almost entirely confined to electrical measuring instruments, and to compass needles.   A magnet has two ends which are very different in character.   If a magnet is suspended so that it can move freely it will always point one end to the north and one end to the south, and they will always be the same ends,   The ends of a magnet are called " poles."   If two magnets are suspended near one another the north pole of one will try to get as near as possible to the south pole of the other.   There is a mutual pull or attraction between the opposite poles of magnets.   Magnets which are made of soft iron and in which magnetism is produced only when an electric current is passing through the surrounding coil are called electromagnets.   The situation of the north or south pole in an electromagnet can always be found by the following rule. If, when one end of the magnet coil is looked at endways, the current is flowing round in the same direction as the motion of clock hands, then the south pole will be nearest the eye.   On the other hand if the current is flowing against the motion of a clock the North pole will be nearest to the eye.

SIMPLE ELECTROMAGNET.

Fig. 26 is intended to show the magnetic effects of electricity. The thing marked N S is a bar of iron round which is wound a coil of wire. Through the coil from left to right is passed a current of electricity. The end of the wire into which the current flows or by which it enters is called the positive end and is marked +. Where the current leaves is called negative and is marked —.
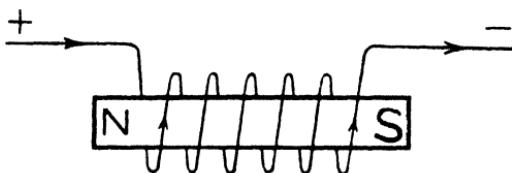
Fig 26.
Simple Electromagnet.

When an electric current passes through a coil of wire wound round an iron bar the bar becomes a magnet for so long as the current is passing. A magnet produced in this way is called an electromagnet.

A magnet has two ends which are different in character. If a magnet is hung up so that it can turn freely, one end, and always the same end, will point to the north. The ends of a magnet are distinguished therefore by being called after the direction in which they would point if able to swing. The ends of a magnet are called "poles."

It is necessary for us to be able to tell without hanging a magnet up or testing it with a compass needle which end will be north and which south. A simple rule enables this to be done. If the magnet coil is looked at from one end and the current is seen to be flowing round the coil against the motion of clock hands then the North pole is nearest the eye. In the diagram in Fig. 26 if we look at the coil from the left the current will be seen to be flowing round against the clock so that the north pole will be nearest the eye, that is on the left in the diagram. If the coil is looked at from the other end the current will seem to be flowing in a clockwise direction, therefore the south pole will be nearest the eye.

In Fig. 27 the coil of wire is wound round the bar opposite handed. If now we look at either end of the coil the rule we have just

learnt will tell us that the north pole is now on the right and the
south pole on the left.
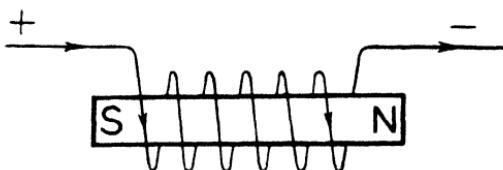
Fig. 27.
Simple Electromagnet.

    *The trick for remembering this rule is, that the ℕorth pole is
nearest the eye when the current flowing in the coil is flowing in a
direction agaiℕst the clock, couℕter clockwise or aℕticlockwise. If the
current is going the 𝒮ame way as the clock the 𝒮outh pole will be
nearest the eye.*

CONDUCTORS AND INSULATORS.

    Electricity flows more easily through some things than through
others.   All metals allow an easy flow of electricity but the degree
of ease of flow varies with the different metals.   Silver allows
electricity to flow easiest, that is to say it offers the least
"resistance" and is therefore said to be the best "conductor" of
electricity.   Silver, however cannot be used much owing to its cost.
Copper is the next best conductor.   It is relatively cheap, reason-
ably strong and hard, easy to bend and work and very ductile so
that it can easily be drawn into wires.   It is used for the wires
or "conductors" of all electrical machines.   Iron and nickel offer
much more resistance and are used for resistance coils where the
object is to limit the flow of current.   (Some of the uses of
resistance coils will appear later.)   Many, in fact, most, non-
metallic objects offer tremendous resistance to electricity.   The
resistance of most of them is so high that they may be looked upon

as " non-conductors " or " insulators." Glass, porcelain and ebonite, rubber, mica, oil and air are the best insulators. Good insulators are just as important as good conductors. It is just as important to prevent the electricity going where you do not want it to go as to send it where you do want it to go. These insulating substances are used for supporting electrical conductors and for wrapping them so as to prevent leakage of current. All these non-conductors or insulators can be punctured or broken down if a sufficient electric pressure or " voltage " is applied. It requires about 20,000 volts. to make a current jump one inch of air. Once, however the spark has formed, the air becomes " ionised " and is a partial conductor and the spark may easily become very long and difficult to quench. This is the reason why a lightning flash can be so long—a mile or more. It does not mean that the voltage in the cloud is of the order of 1,000,000,000 volts. Once the resistance of the air has broken down the spark can spread without it being necessary to have a voltage of anything like 20,000 to the inch. For this reason it is necessary that switches, which are the " taps " used for turning on and off electricity, should be provided with some way of quenching the spark. The most general way now used for indoor medium current switches is to immerse the contacts in oil.

PRESSURE AND QUANTITY—VOLTS AND AMPERES.

Before attempting to see how electricity is made and what it does we must consider how it flows through its wires and conductors. The flow of electricity through a wire is very like the flow of water through a pipe. For a particular wire or pipe the higher the pressure the faster will be the flow. And, for a particular pressure the larger the wire or pipe the greater will be the flow.

The pressure of electricity is called the " Voltage " and is measured in units called " Volts." (A compliment paid by the world's engineers to the memory of Volta an Italian scientist who, in 1800, made the first electric chemical cell or battery.)

The quantity of electricity flowing is measured in units called " Amperes." (A compliment to the memory of the French scientist Ampère who in 1820 first worked out the mathematics of electro-magnetism.)

OHM'S LAW.

The difficulty which an electric current experiences in flowing along a wire depends on the size of the wire, the metal from which it is made and upon its temperature. The law which the flow of electricity obeys was discovered by a German professor called Ohm

in 1827.   His discovery was so coldly received by the scientists of
the world that Ohm resigned his professorship in a huff.   Ohm's
law is quite simple and states two simple facts.   The first is that
the flow of current will be directly proportional to the voltage or
pressure.   The second is that the flow of current will be directly
proportional to the ease of flow or exactly opposite to the resistance.
Ohm's law states that the current (amperes) flowing in a circuit will
vary directly as the pressure (volts) and inversely as the resistance
(ohms).   This means that if the volts are doubled the current flowing
will be doubled.   If the ohms—units of resistance—are doubled the
current flowing will be halved.   If any two of the three values are
known the other can be found from Ohm's law quite simply.

$$\text{Current flow in Amperes} \quad = \quad \frac{\text{Pressure in Volts}}{\text{Resistance in Ohms}}$$

$$C = \frac{V}{R}$$

$$\text{Resistance in Ohms} \quad = \quad \frac{\text{Pressure in Volts}}{\text{Current in Amperes}}$$

$$R = \frac{V}{C}$$

$$\text{Pressure in Volts} \quad = \text{Current in Amperes} \times$$
$$\text{Resistance in Ohms}$$
$$V = C \times R$$

Suppose an electric light bulb is working on a 220 volt circuit
and suppose it is using a quarter of an ampere, then the resistance of
the lamp (the resistance of the other wires in the circuit is negligible
compared to that of the lamp and can be ignored) is 220 divided by
one quarter, or 880 ohms.

POWER—WATTS.

The power flowing in an electric circuit is the quantity
multiplied by the pressure, that is to say the amperes multiplied by
the volts.   These power units are called Watts.   (James Watt did
no work on electricity, but he was the real father of power, so his
name has been given to the unit of electrical power.)   Suppose 1
ampere flows through a circuit at 100 volts pressure, the electrical
power in the circuit is 1×100, that is 100 watts.   Again suppose 10
amperes flow in a circuit at a pressure of 10 volts, this again is a
power of 100 watts, so also is 100 amperes at 1 volt.   Now let us
examine the different ways of having the same power in a circuit.
If we want to use a power of 100 watts we can do it with 100
amperes at 1 volt or 1 ampere at 100 volts.   Now from Ohm's law

we can find out what the resistance must be for our circuit in each case and we find that the 1 volt circuit will require a resistance of 1/100 ohm to pass 100 amperes while the 100 volt circuit will pass 1 ampere if the resistance is 100 ohms. This means that the resistance of the high voltage circuit will be 10,000 times as great as the low voltage circuit, which means that the wires in the low voltage circuit must be 10,000 times as big as in the high voltage circuit. The advantage of a high voltage is at once clear. The higher the voltage the smaller can be all the wires and conductors in the circuit. Two difficulties prevent the use of very high voltages except for special purposes. The first is the difficulty of making switch gear which will break a very high voltage current without such bad sparking that will burn the switch. The second is the danger of leakage. The high voltage circuit requires very expensive and elaborate insulation. Another disadvantage of very high voltage is the danger to life from electric shock. The human body has a certain resistance which varies considerably with the moisture of the skin, etc. In order to produce death the voltage of the supply must be sufficient to pass about 100 watts through the body. The electric chair in American prisons is supplied with 2,000 volts. In ordinary circumstances with dry hands, etc., a supply of a 100 volts is safe, 200 risky, 400 dangerous and 500 or over exceedingly dangerous.

KILOWATTS.

The watt as a unit of power is inconveniently small for many purposes so the unit used is the "kilowatt" or 1,000 watts (Greek, kilioi—1,000). Watts are used for the measure of small powers and kilowatts for large powers. For example the four biggest turbines at Barking are 75,000 kilowatts each. The Plaistow Wharf turbo-generators are 4,500 kilowatts. A small electric radiator is half a kilowatt. An ordinary electric light bulb is 30 watts. A powerful loud speaker is 2 watts. Three quarters of a kilowatt is one Horse Power.

BOARD OF TRADE UNITS.

Work done must be measured over a time because watts or power is simply a measure of the rate at which work is being done. The unit of electrical work is the Board of Trade Unit which is 1000 watt hours. That is to say a current of 1 watt flowing for 1000 hours, a current of 1000 watts flowing for 1 hour, or any other combination of current and time, which multiplied together give 1000 watt hours, or as it is generally called a kilowatt hour.

HEATING EFFECT OF ELECTRICITY.

On page 91 it was explained that heat and energy are inter-

changeable. Electrical energy can be made use of either as mechanical power or as heat. Just as the inefficiency of a steam engine is measured by the amount of heat it wastes, so the inefficiency of an electrical machine is also measured by the amount of electrical energy that it converts into heat compared to the amount it turns into work. When electricity passes along a conductor or wire it always heats up the wire a little bit, however large the wire, and that heat is lost energy. The amount of heat that is produced in an electrical circuit is proportional to the resistance of the circuit and varies as the square of the current, that is to say ; a current of 2 amperes has a heating effect 4 times as great as a current of 1 ampere ; and a current of 3 amperes has a heating effect 9 times as great as one of 1 ampere. This means that while it is a good thing to keep the resistance of a circuit as low as possible it is even more important to keep the current as low as possible. The resistance of an electrical machine is generally dependent on a number of other considerations and a heat loss of some amount will always take place. But wires and cables distributing the current can and should be large and of low resistance. Clearly here is another argument for using the highest possible voltage. For the same power the higher the voltage the less the amperage. For long transmission lines low voltage would be quite out of the question. Actually very high voltages are used. Most electricity is used at about 220 volts. The current is generated in the power station at about 11,000 volts. It is then stepped up to 132,000 volts by means of a transformer if it is to be fed into the main British grid. It is stepped down on reaching its destination to probably 3,300 volts and stepped down again at the corner of the street to 220 volts. At 132,000 volts the current in amperes is only one six hundredth of the current for the same power at 220 volts. (See Chapter 17).

THE GENERATION OF ELECTRICITY—SIMPLE DYNAMO.

When a bar of iron or steel which has been magnetised is hung up by its middle, one end and always the same end points to the north. This end of the magnet is called the north pole and the other end is called the south pole. On pages 120 and 121 it has been explained how it is possible to find out where the poles of an electro-magnet will be. If a bar of iron which is to be a magnet is bent into a horseshoe shape the two poles are quite near to each other and the " magnetic field " as it is called is very strong. In the space between the poles of such a horse-shoe magnet let us mount an iron drum on an axle so that the drum can rotate with its edge very close to the magnet poles without touching them. By placing an iron drum between the magnet poles the magnetism will be still more concentrated into the spaces between the poles and the drum. An

iron drum lying between the poles of a magnet is called an armature (the word means defence—used because the armature is a defence against loss of magnetism). Now round this armature drum let us put a loop of wire. Not round the middle like a cask hoop but down one side, across one end and back the other side. Let each end of the wire be attached to a " slip-ring." This is an insulated ring on the axle against which a metal or carbon " brush " can rub so as to make electrical connection with the slip-ring.

Now if the drum is turned or rotated one arm of the wire loop will be passing through or " cutting " the magnetic field near the north pole and this will cause a current of electricity to flow in the wire. At the same time the other arm of the wire will be cutting the magnetic field near the south pole of the magnet, and this will cause a current to flow in this arm of the wire loop. The two currents generated will be in opposite directions, but as the wires are just the two sides of a continuous loop the currents will be in the same direction round the loop. This may seem very complicated, so consider : when runners on a race track get spread out the leaders may well get half a lap ahead when they will be running in the opposite direction to the others although all are running the same way round. In just the same way the current generated by the north pole will be going in the same direction along the wire loop as the current generated by the south pole which will be in the opposite direction with regard to space but in a continuous circuit as regards the wire loop.

' The voltage of the current generated in the wire loop is proportional to the strength of the magnetic field and the speed at which it is cut. Suppose that the magnet is sufficiently strong and that the speed is such that each conductor, that is each arm of the loop generates 1 volt, then the voltage of the whole loop as measured at the slip rings will be 2 volts. Now if we wind the wire round the drum 10 times instead of once before connecting the ends to the slip rings, we shall get one volt generated in each wire which means that each side will give 10 volts or a total at the rings of 20 volts. Now we can make our magnetism stronger by making our gap between the magnet poles and the armature as small as possible and by shaping the poles to part of a circle so that the armature drum rotates as near them as possible without touching. In order to reduce the " air gaps " between the magnet poles and the armature still more the wires on the armature are wound in slots. These slots provide a simple way of driving the wire loops round, which would be quite a problem on a smooth drum. Now by making all these improvements in our magnetic " circuit " we may find that instead of each wire giving only 1 volt each wire may give 5 volts so that if our coil still has 10 turns then the voltage at the slip rings will be 100 volts.

The direction in which current will flow when a wire is moved in a magnetic field is found from Fleming's rule. (Fleming was Professor of electrical engineering at London University for 40 years until 1926. He invented the thermionic valve upon which all modern radio development depends). If the thumb, first finger and middle finger of the RIGHT hand are all held at right angles to one another, and if the hand is held in such a way that one finger points in the direction of motion of the wire, the other points to the south pole, then the thumb or the remaining finger will point in the direction in which the current will flow.

ALTERNATING CURRENT—A.C.

Let us examine just exactly what happens when the armature drum carrying a single loop of wire on it makes one complete turn. Call one slip ring " a " and the wire which forms one half of the loop, and whose end is attached to slip ring " a," "A." Call the other slip ring " b " and the wire connected to it " B." Wires "A" and " B " are of course just the two arms of a single loop. We will start with the drum in such a position that the loop of wire is lying exactly halfway between the north and south poles. There will be little or no magnetism there. As the drum begins to turn the wires will begin to cut magnetism which will gradually get stronger as they get nearer the middle of the magnet poles. So at starting there will be no current in the loop but as wire "A" gets nearer the middle of the north pole wire " B " is also getting nearer the middle of the south pole. The voltage in both wires will follow the same way round the loop. Current generated in wire "A" will flow to slip ring " a " and current generated in wire " B " will flow round through "A" to slip ring " a " too. Slip ring " a " will be what is called the positive—that means that electricity will flow from the positive " a " ring round through any circuit that we choose to connect to the slip ring brushes and back to the negative or " b " slip ring. Now when the armature goes on with its rotation the wires will leave the region of the poles and approach the region between the poles that is poor in magnetism. This means that the voltage of the current that is being generated in the two arms of the wire loop gradually rises to a maximum and then falls away to nothing when the wires are cutting no magnetism between the poles. Now as the armature drum continues to rotate the wires will again approach the middle of the poles where there is a lot of magnetism and the voltage will rise in the wire. But this time wire " B " is approaching the centre of the north pole so that slip ring " b " will be positive and slip ring " a " will be negative. The voltage will reach a peak again in the new direction and again fall to nothing when the wires reach the between pole position. It is now quite

clear that the current we are generating "alternates," or goes first in one direction and then in the other, and is like a wave pulsing from nothing to a maximum and then falling to nothing to rise to a similar maximum in the opposite direction. This complete "cycle" takes place each time the armature makes one complete revolution past the two poles of the magnet.

FREQUENCY.

If we drive our wire carrying armature drum at 3000 revolutions a minute we shall get 3000 cycles or waves of current per minute—that is 50 cycles per second. The meaning of such phrases as " a current of 50 cycle frequency " or " a current of 25 cycle periodicity " is now clear. If we ran our armature at 1,500 r.p.m. we should get a current whose frequency was 25 cycles. On the other hand if we had four poles on our magnet, alternately north and south our wire loop would cut the altering magnetism twice as often and if driven at 1,500 r.p.m. we should from such a machine get 50 cycle current. The standard frequency of the British Grid is 50 cyles. Plaistow Wharf for many years ran with 25 cycle current. The lower frequency is an advantage if most of the motors on the supply are to be slow running. Just as a generator with two poles and running at 1,500 r.p.m. produces 25 cycle current, so will a two pole motor, when supplied with a 25-cycle current, run at 1,500 r.p.m. This is the maximum speed at which such a motor can run and is called the " Synchronous " speed. (Two Greek words, sun—with, chronos—time, meaning in time or in step). The maximum speed of a 50 cycle motor is 3,000 r.p.m.

PHASES.

We have seen that with one coil or loop of wire on the armature the voltage falls to nothing each time the coil is half way between the poles. If we provide two more slip rings and wind another coil of wire round the armature at right angles to the first we can get the maximum current flow in the second, or new, coil when there is no current in the first. Because if the first coil is between the poles the new second coil must be opposite the middle of the poles. Our dynamo is now a " two phase " machine instead of a " single phase " machine. (The word phase means a " compulsory appearance " from the Greek verb phasein—to make appear.) Single phase current is not very useful because single phase motors are just as complicated as D.C. motors (D.C. will be discussed in a moment) and D.C. current is more generally useful than single phase A.C. current. Two phase motors on the other hand work on quite a different principle and are simple, reliable and cheap. But a two phase supply needs four wires. Three phase current is therefore used almost

universally. For a reason which will be described in a moment three phase current only requires three wires to carry it while three phase motors have all the advantages of two phase motors. It is desirable to try to understand how it is that three phase current needs only three wires.

If on the armature we wind three equally spaced coils they will occupy the following positions relative to a clock face. The first will be at 12 and 6 o'clock, the second at 4 and 10 and the third at 8 and 2. Now let us consider only the "A" wires in each of the coils or loops. We will call them A12, A4 and A8. These are their positions at the start of turning the armature round. We will suppose that the centres of the magnet poles are at 12 and 6 o'clock. Then at the start A12 will be cutting the greatest magnetism under the north pole, while A4 and A8 will be entering and leaving the magnetism of the south pole. Each of these wires will be generating just half the current that the A12 coil is generating and the current will of course be in the opposite direction. So that the combined voltage in all the coils together cancels out and is zero. If any other position of the armature is taken it will be seen that exactly the same thing occurs. The voltage in the phase that happens to be greatest is always exactly equal and opposite to the combined voltages in the other two phases. This means that we can connect one end of each of the phase coils together at a common point and that as the simultaneous voltage of all the phases is always zero there will be no currentflow at the common point and no interference of one phase by another. This is very convenient. We connect one end of each phase coil together and lead the other ends out to three slip rings. We now have all the advantages of two phase current and we only need three wires. The advantages of more than one phase will be clear when we come to consider electric motors.

MAGNETIC FIELD.

The diagram in Fig. 28 shows how the magnetic pull is arranged round a magnet.   The lines are, of course, imaginary and can be drawn by placing a small compass needle in all positions round the magnet. In the diagram the compass is shown in three different positions.   A compass needle is a small permanent magnet, and magnets free to move always arrange themselves so that the north pole of one is pointing to the south pole of the other.   The magnetism is very strong near the poles but very quickly thins out and gets weaker further away from the actual poles.
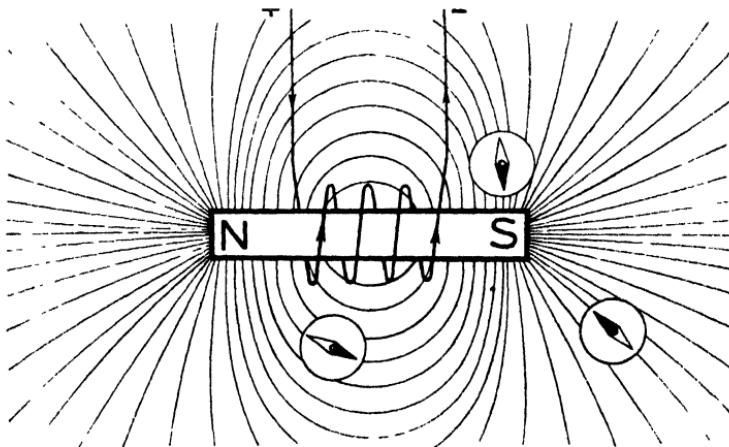
Fig. 28
Magnetic   Field   Round   an   Electromagnet.

An electric current passed through a coil of wire that is wound round an iron bar makes the iron bar into a magnet.   Electricity is made in a wire that " cuts " or moves through a " magnetic field " or area near the poles of a magnet.   Before we can consider how a machine for producing electricity works we must first see whether it is possible to arrange our magnet so that as little as possible of its magnetism is dissipated.   In Fig. 28 the magnetism seems to be radiating in all directions.

*If the iron bar that is to be used as the magnet is bent into the shape of a
horseshoe, as shown in Fig. 29, the magnetism is very much better
concentrated.   But there is still a lot that is dissipated.*
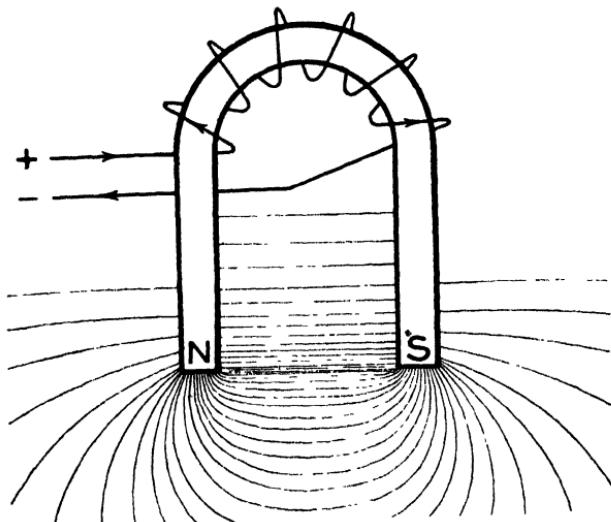
Fig. 29
Horseshoe Electromagnet.
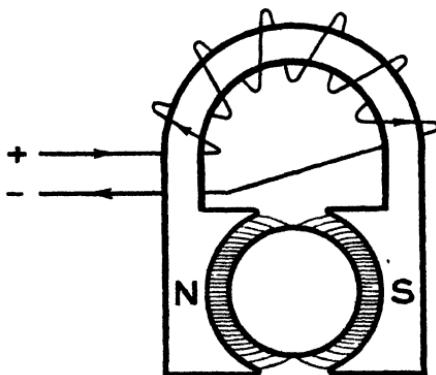
Fig. 30
Improved Horseshoe Electromagnet.

Fig. 30 shows an improved electromagnet. The poles have been provided with shaped pole pieces and an iron drum or armature has been placed between them. The magnetism is now concentrated into a very small area, namely the " air gap " between the pole pieces and the armature. The word armature means a protection or defence. It was first used for the small piece of iron that bridges the poles of a steel permanent magnet to prevent loss of magnetism. It will be noticed that the magnetism is strongest where the magnetic path is the shortest, namely, across between the middles of the poles. Midway between the poles there is practically no magnetism. The magnetism has been greatly increased in strength not only by giving it a good easy path but by reducing the amount of air it has to cross.

SIMPLE GENERATOR.
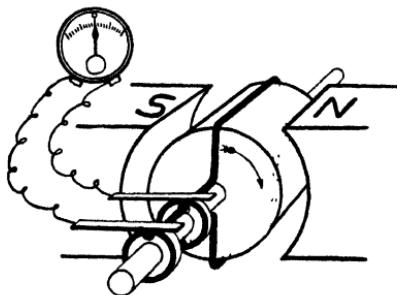
Fig. 31
Simple Generator.

Fig. 31 represents the simplest form of electric generator or dynamo. This diagram, or slight modifications of it will appear frequently on the following pages so it is important to try to understand just what the diagram is intended to show. We are looking obliquely on the pole pieces and armature of an arrangement similar to that shown in Fig. 30. The greater part of the magnet and the coil which does the magnetising have been left out of the picture for simplicity. S and N are the curved pole pieces of a horseshoe shaped electromagnet. Mounted on a shaft or spindle so that it can rotate between the pole pieces is an iron drum or armature. The bearings which support this drum have been omitted from the diagram for simplicity. The thick black line is a loop of wire wound round the armature—its path across the far end of the drum is shown dotted. The ends of the wire are connected to two metal rings called " slip rings " mounted on but insulated from the shaft. The top side of the wire goes under the inner ring and is attached to the outer or left hand ring. The under side of the wire loop is attached to the inner ring. Bearing on each ring is a fixed rubbing piece called a " brush," which is generally made of carbon, to make an electrical connection with

the moving slip ring. These brushes are shown in the diagram as flat strips. Attached to the brushes are wires leading to a voltmeter, an instrument which will read volts. This particular instrument has its zero point in the centre of the scale so that not only can the voltage changes be seen, but any change in the direction of the current. The iron drum, wire loop, slip rings and shaft are all fastened together so that if the shaft is turned the whole thing will go round together. An electric current is made to flow in a wire when the wire is moved through magnetism. A dynamo or generator is just a machine for moving wires through very concentrated magnetism. Before following the armature through a turn we must learn the rule which tells us which way the current generated will flow. This is known as Fleming's rule.

Fig. 32
Fleming's Rule for Generators.

If the thumb, first finger and middle finger of the RIGHT hand are held so that all three are at right-angles to one another, and if the first or pointing finger is pointed from north to south, and if the thumb is pointed in the direction in which the wire is being moved, then the middle finger will show the direction in which the current will flow. Fig. 32 shows the application of Fleming's rule to our diagrammatic armature. In Fig. 32, the rule is being applied to the wire as it is passing the south pole. Let us imagine how it works if we apply it to the wire passing the north pole. The first finger must still point in the same direction, from north to south. But the wire is moving downwards so that the hand will have to be turned right round in order that .the thumb can point that way. The middle finger will then be pointing in the direction of the current flow, which will be away from us.

It will be noticed that the current in the two wires is flowing in opposite directions, but that, owing to the wires forming the two halves of the same loop, the current is flowing the same way round the loop, just as runners on a race track are all running the same way round even if the leaders are half a lap in front and are actually running in the opposite direction to the tail of the field.
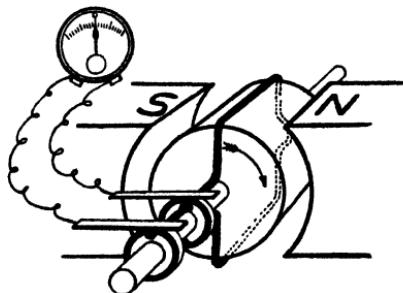
Fig. 33
Simple Generator.

Fig. 33 is the diagram of our little generator again repeated so that it is not necessary to turn back the pages. The armature is being turned in the direction of the arrow. In the position in which the wire loop is shown there is little or no magnetism. Therefore there will be no current and the voltmeter will show zero.
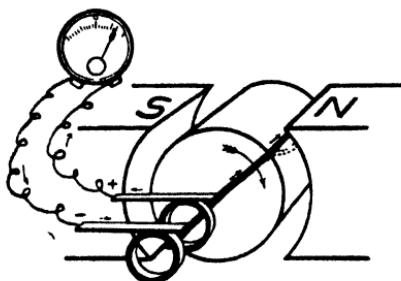
Fig. 34
Simple Generator.

In Fig. 34, the armature has turned an eighth of a turn and the wire loop is cutting magnetism—not the strongest magnetism but about two-thirds of full strength. Fleming's rule tells us the direction in which the current will be flowing, and arrows on the diagram show this direction. The wire under the north pole is attached to the left-hand outer slip ring, and the wire under the south pole which cannot be seen in this view is attached to the inner ring. The shaft has been omitted for simplicity.
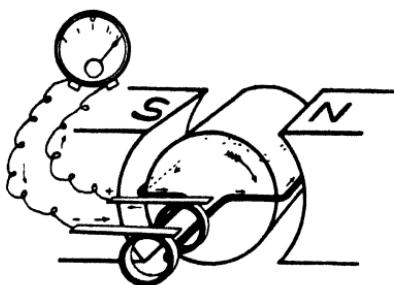
Fig. 35
Simple Generator.

Fig. 35 shows the armature after making another eighth of a turn. The wire loop is horizontal and is right in the middle of the strongest magnetism. The voltage is therefore at its greatest.
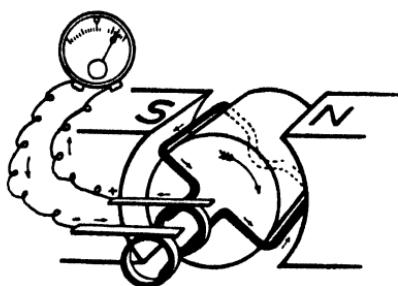
Fig. 36
Simple Generator.

Fig. 36 shows the armature after a further eighth of a turn. The wire loop is just about to get into the region of weak magnetism. The current is still fairly strong in this position and is, of course, still in the same direction as in the last two figures.   .

In Fig. 37, the wire loop has completed its first half turn and the two wires of the loop are again midway between the magnet poles.   The wires are cutting no magnetism so that there is no current being generated and the voltmeter is showing zero.
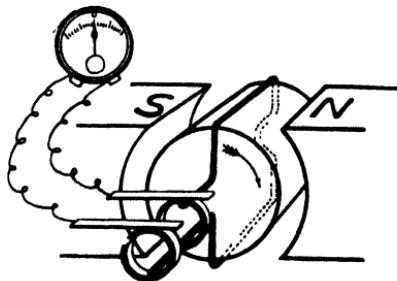
Fig. 37
Simple Generator.

In Fig. 38, the armature is shown after it has made another eighth of a turn.   The loop of wire is in exactly the same position as it was in Fig. 34 after it had made its first eighth of a turn.   There is, however,
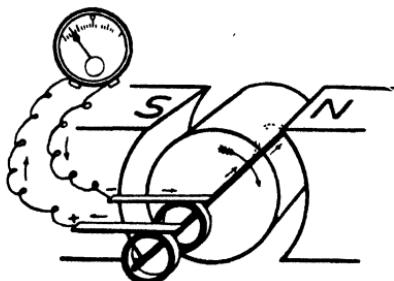
Fig. 38
Simple   Generator.

one very important difference.   Hitherto, the nearest or left-hand slip ring has been connected to the wire passing the north pole.   But now, this wire is approaching the south pole.   This means that the slip rings have changed their character.   Instead of current flowing out from the inside slip ring and back to the left-hand slip ring, the current is now flowing in the opposite direction and is flowing from the left-hand ring through the voltmeter and back into the inside slip ring.   The amount of the current being generated is the same as in Fig. 34 but the direction is reversed as is shown on the voltmeter.

In Fig. 39, the armature has turned to the position where the wires are cutting the greatest magnetism.   The current is therefore at its highest, as is shown by the voltmeter.
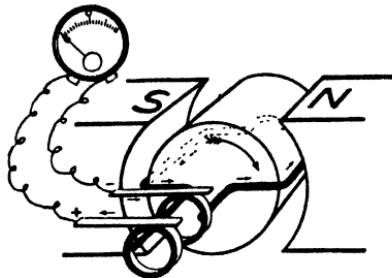
Fig. 39
Simple   Generator.

Fig. 40 shows the armature when it has nearly completed its full turn and the voltage is dropping.   After the next eighth of a turn it will have got back to its starting point and the voltage will have dropped to zero.
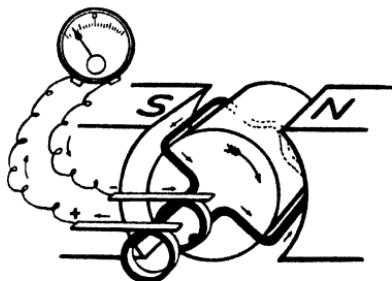
Fig. 40
Simple   Generator.

If the wire is wound several times round and round the armature before coming out to the slip rings, the voltage will be increased in proportion to the number of turns.   The voltage generated in any one wire is proportional to the strength of the magnetism that it cuts and the speed it cuts it.

If our voltmeter had been very sensitive and we had been very clever at reading it we could note the voltage at every point in the complete revolution of the armature. We could then, from these voltmeter readings, draw a line which would show the way in which the voltage waxes and wanes and the way in which it changes direction. Fig. 41 shows such a diagram. It shows the voltmeter readings at the eight positions that we considered our loop of wire to occupy. It will be quite clear now that when a loop of wire makes one complete turn past the two poles of a magnet that the current in the loop gradually rises to a maximum in one direction, then falls gradually to zero and again rises to an identical maximum in the opposite direction. The current flows in alternate directions and is therefore called " alternating " current, or A.C. It goes through this " cycle " every time it passes a pair of poles. If the magnet is like that in our diagrams with two poles the current would make 50 "cycles," or alternations, each second if the armature carrying the loop of wire were driven at 3,000 revolutions per minute.
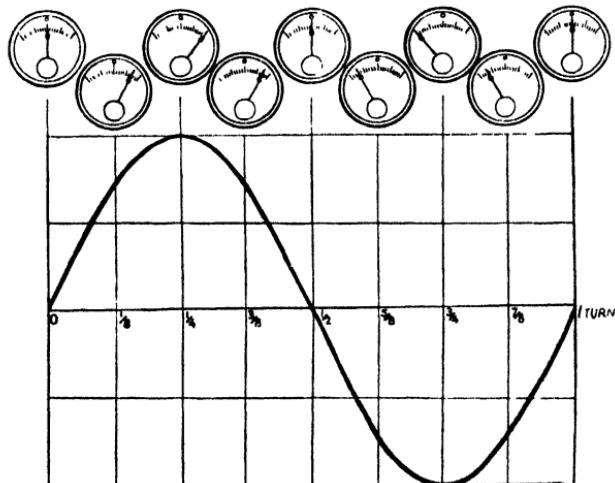
Fig. 41
Alternating   Current.

If there is only one coil or winding on the armature the current is only compelled to appear once each revolution, and is called a single phase current—phase means a compulsory appearance. It is clearly possible to wind another coil or loop on the armature in such a position that when the first loop is generating no current when the loop is in between the poles, the new second coil is cutting the strongest magnetism under the middle of the pole pieces.

This means that when one loop is generating its greatest current there will be no current in the other loop.   Fig. 42 shows a diagram of such an armature.   The black loop is connected to the two inside slip rings, and the striped loop is connected to the two outside or left-hand rings.
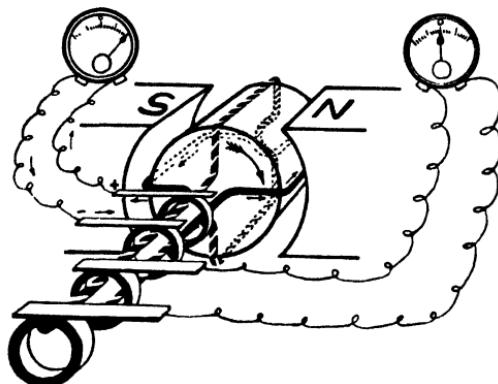
Fig.   42
Two Phase   Generator.

Each coil will go through exactly the same cycle in one whole revolution, but when the current is at its greatest in one coil it will always be zero in the other.   The two current curves when drawn out on the same sheet of paper will look like this—Fig. 43.
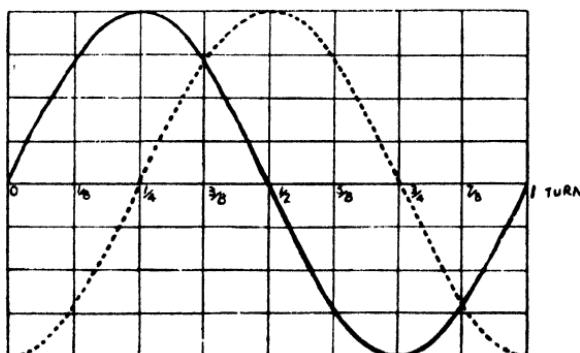
Fig. 43
Two-Phase Current.

It will have been noticed that it is necessary to use four slip rings to collect this " two-phase " current, as it is called. It also needs four wires to carry it. Fig. 43 seems to cry out for another curve to fill up the gap and make the current be generated smoothly all the time.
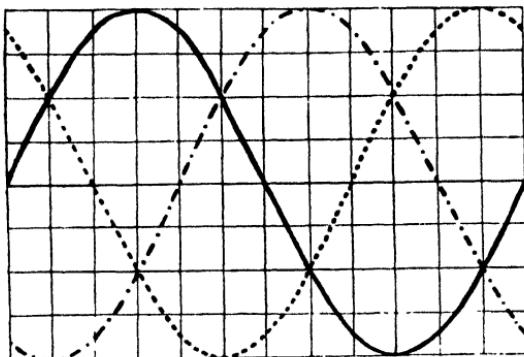
Fig. 44
Three-Phase Current.

Fig. 44 is a diagram of what is called a " three-phase " current. It is the current that is generated by three equally spaced armature coils. Before looking at the diagram of an armature wound with three loops or coils there is something very interesting and important that we can see from the current curves in Fig 44. The curve shows the voltage in each phase at any point in one complete turn of the armature. Each square from left to right represents a part of a turn of the armature equal to five minutes on a clock face. We call each square up and down equal to 10 volts. At the extreme left-hand edge of the diagram, the black phase shows 0 volts. The dotted phase shows + 35 volts, and the dot and dash phase shows — 35 volts. So that the simultaneous voltage of all the phases together is 0. Now let us move one square along to the right. The black phase and the dotted phase each show + 20 volts. The dot and dash phase shows — 40 volts. The simultaneous voltage in all the phases combined is 0. And so it is at all points in the diagram. The simultaneous voltage of all three phases in a three-phase current is always zero. This means that we can join the ends of the three phase-coils to one common point and connect the other ends to three slip rings. From these three slip rings three wires can carry the current.

Fig. 45 is a diagram of a three-phase generator. The top wire in the black phase coil comes to the outside or left-hand slip ring. The right-hand wire of the striped phase coil is connected to the middle ring, and the left-hand wire of the criss-cross phase goes to the inner slip ring.
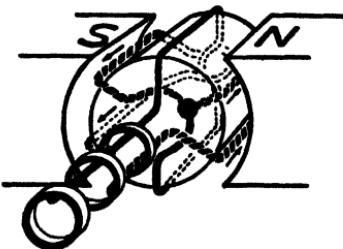
Fig. 45
Three-Phase Generator.

The other ends of the coils are connected together on the end of the armature nearest to us. From what we have seen of the working of a single-phase machine it is clear that in this diagram the black phase is generating no current and each of the other phases is generating the same amount of current but in opposite directions. Three-phase current is in almost universal use nowadays because three-phase motors have all the advantages of two-phase motors, and a three-phase supply only needs three wires whereas a two-phase supply requires four.

ALTERNATORS AND GENERATORS.

The dynamo that generates the alternating current that we have been considering is usually called an alternator. Sometimes it is called a generator, it is never nowadays called a dynamo. For certain practical reasons the alternators in power houses are a bit different from the simple machine we have been considering. So long as magnetism is cut by wires it does not matter whether the

wires rotate through fixed magnetism or whether magnetism rotates past fixed wires. All the modern alternators are made with fixed armatures and rotating magnets. The magnet is an easy thing to make strong and robust. But the chief reason for rotating the magnets is that only two slip rings are required and these only have to carry the comparatively weak magnetising current and therefore give less trouble than would three or more slip rings carrying the whole output of the machine. Alternators, such as those at Plaistow Wharf, which run at 3000 r.p.m. to give a 50 cycle current only have two poles in their magnets. If we wish to get 50 cycle current from a slower machine it must have more poles on its magnet, which then looks like a wheel with heavy thick spokes and no rim—each of the spokes being a magnet pole, carrying a coil to magnetise it. The speed at which an alternator must run to give any particular frequency is found by multiplying the frequency by 60 and dividing by the number of PAIRS of poles.

TABLE VII.

NUMBER OF POLES AND SPEED OF ALTERNATORS.

50 CYCLES.

Number of poles.	Number of pairs of poles.	Alternator Speed r.p.m.
2	1	3000
4	2	1500
6	3	l000
8	4	750
10	5	600
12	6	500
14	7	429
16	8	375

GENERATORS.

Fig. 46, while still diagrammatic, is much more like the real thing in generators than the diagrams we have been considering. Looking at the magnet first, we see that by making the magnet frame circular in shape

it is possible to put inside it as many pairs of magnet poles as we wish.
If it is not clear why this should be so, the six magnet poles shown in
the figure can be looked upon as six very sharply bent magnets with their
like poles touching.   In the simple generator we have hitherto been
considering the loop of wire on the armature had to rotate 50 times a
second so as to pass a pair of poles 50 times a second in order to make
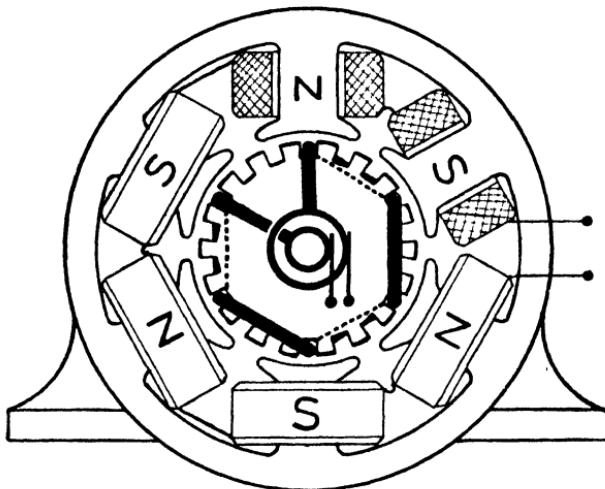
Fig. 46
Six-Pole   Rotating   Armature   Generator.

50 cycle current.   On the machine shown here there are three pairs of
poles, and the armature carries three loops or coils to each phase, each
of the loops being so spaced round the armature that when one loop is
under a pair of poles the other two loops in that phase are also
under a pair of poles.   It will be seen that the loops are carried in
slots in the armature.   This gives a good simple drive to the wires and
it also greatly lessens the air gap that the magnetism has to cross.   Only
one phase coil has been shown, for simplicity, but the armature slots
for the other two phases are there.   It will be seen that all six wires in
the phase shown are cutting the strongest possible magnetism right in
the middle of the pole pieces.   In imagination, let us turn the armature
so that the wires at present under the north poles will be under the south
poles.   This means that the current will again be at its greatest but in
the opposite direction.   If we turn the armature a little further the
wires will soon be back under the same kind of poles that they started
under, but they will be one-third of a turn further round.   This clearly
means that three cycles of current will be obtained for each revolution

of the armature.   It follows that such a machine would only have to run at 1,000 r.p.m. to give a 50 cycle current.   By varying the number of poles we can get the frequency we want within certain limits to suit the kind of machine with which we are generating.   For example, a steam turbine is efficient at very high speed.   So we give the magnet two poles and run the machine at 3,000 r.p.m.   If we have a big water turbine which runs efficiently comparatively slowly, we put in 32 poles and run our generator at 187½ r.p.m.   The rule for the speed of an alternating current machine is 60 multiplied by the frequency divided by the number of pairs of poles.

Coils of wire round the magnet poles cause the magnetism to be produced.   The circular shape of the machine shown in Fig. 43 is very practical, apart from electrical consideration.   It acts as a frame for the whole machine, and everything can be machined truly and easily.   The current for energising the magnets must be direct current in order to keep the poles always of the same polarity.   This magnetising current can be obtained from any convenient source.   It is usually obtained from a little d.c. generator on the end of the main generator shaft.   The magnetising current need never be more than 5% of the main current.
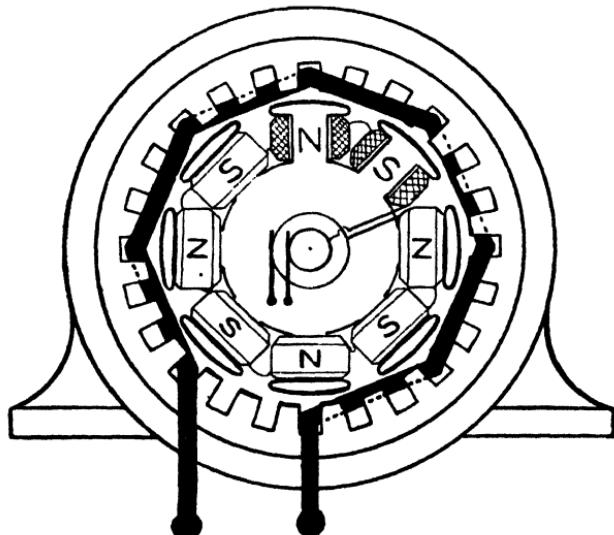
Fig. 47
Eight-Pole   Rotating   Magnet   Generator.

Fig. 47 shows a generator where the magnet and armature have changed places.   The magnet revolves inside a stationary armature.   Under these circumstances, the revolving magnet is usually called the rotor and the stationary armature is called the stator.   This is the arrangement used universally nowadays, because instead of the whole output of the machine having to be taken out through slip rings and brushes—a rubbing electrical connection is always troublesome—only the small magnetising current has to be put in.

The machine shown in Fig. 47 has four pairs of poles and for 50 cycles has to run at 750 r.p.m.   Only one phase is shown on the diaqram for the sake of clearness.

DIRECT CURRENT—D.C.

Alternating current motors are not ideal where much speed variation is desired.   They also do not make very good crane or lift motors.   Alternating current cannot be stored in an electrical accumulator.   It is quite a simple matter to modify the electric generator so that it will give a direct current—that is one that does not alternate but is continuous in one direction.   Direct Current or D.C. for short, is excellent for working cranes, lifts, trams, trains and things where the speed is frequently changing.   It can be stored in an accumulator.   D.C. machines are however more complicated and less robust and reliable than A.C. machines.

Consider our simple one loop dynamo and instead of slip rings let us fit one ring cut in half across its diameter so that it looks something like this ⊂⊃.   Now if we attach the ends of our wire loop to these segments and fit two brushes rubbing against our split ring at opposite sides, we shall get a current that is always flowing in the same direction—D.C.   This requires a little puzzling out.   Call one segment of the split ring or " commutator " as it is called, " a " and let the wire "A" on the armature be attached to it. The return wire " B " is fastened to segment " b."   The two brushes " Z " and " Y " are placed in line with the magnet poles.   Now as before let us follow one complete turn of the armature, starting in the position where the wires are between the poles and no current is being generated.   The brushes will have a part of each commutator

segment under each of them. This does not matter because no current is passing. As the armature rotates wire "A" cuts magnetism at the north pole and wire " B " at the south pole. At the same time the commutator segments will have moved so that segment " a " is under brush " Z " and segment " b " is under brush " Y." Current will flow from wire "A" through segment " a " to brush " Z " which will be the positive brush. The current generated by wire " B " will add itself on to "A's " current. The current will rise to a maximum as the wire passes the middle of the poles and will fall back to zero as the wires come midway between the magnets. As the armature continues to rotate, wire " B " will approach the north pole and at the same time segment " b " will come under brush " Z." Current will flow from " B " direct through segment " b " to brush " Z " and current will also flow along "A" and round through " B " and out to brush " Z." It will be seen that brush " Z " remains positive because it is always connected directly through the commutator to the wire that is passing the north pole. So now we have a current which rises from zero to a maximum and falls to zero again but which never changes direction. If we add extra coils to the armature like extra phase coils we can fill up the gaps in our current curve by always having one wire passing through the strongest magnetism. But the commutator must be cut up into smaller pieces so that there is one segment for each wire. These extra coils on a D.C. armature are very like the extra phase coils in an alternator but as the current never changes direction the currents in the different coils can all be piled one on top of the other so as to give a practically smooth continuous output current at the brushes.

SIMPLE D.C. DYNAMO.

We have seen how an alternating current is generated. For many purposes such a current, which is continually changing direction, is unsuitable. For example, for use in energising an electro-magnet, for nickel and chromium plating, for driving lifts and cranes and for trams and railways a continuous or direct current is wanted. This continuous current, or D.C., is obtained from a generator just like the generator that has been described and which we have seen gives an alternating current. The only difference is that the slip rings are replaced by a thing called a commutator. (Commutation means changing from one state to another.) In the diagrams that follow, the simplest possible form of two-part commutator is shown. It consists

of a ring split across its diameter with each part insulated from the shaft and from the other.   Each half, or segment, of the commutator is attached to one end of the loop of wire wound round the armature.
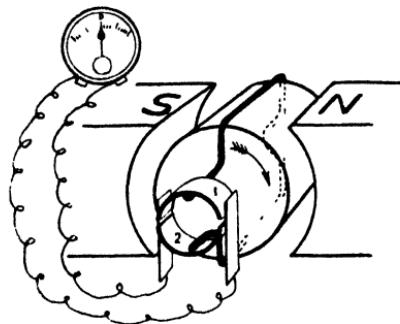
Fig. 48
Simple Direct Current Dynamo.

In Fig. 48, the wire loop is in the position where no current is being generated.   The two brushes, one on either side of the commutator, are bearing equally on each of the two commutator segments.
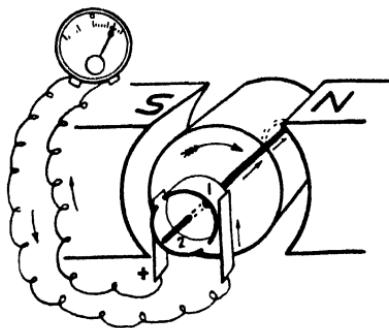
Fig. 49
Simple D.C. Dynamo.

In Fig. 49, the wire loop is well into the magnetism.   A current is being generated.   From Fleming's rule segment 1 must be negative so that current will be coming out of the left-hand brush, going round through the voltmeter and back into the negative right-hand brush.

In Fig. 50, the wires are cutting the strongest magnetism and therefore generating the greatest current.
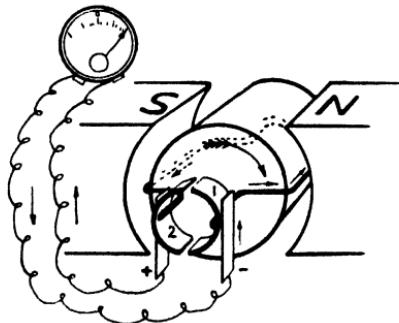
Fig. 50
Simple D.C. Dynamo.
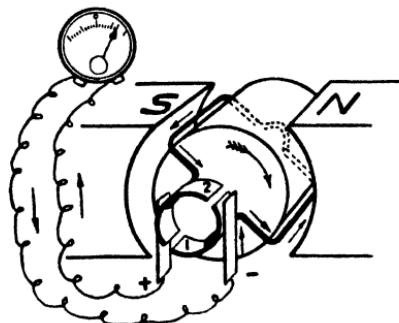
Fig. 51
Simple D.C. Dynamo.

In Fig. 51, the wires are cutting less magnetism so that the current being generated is getting less.   It will be noticed that the commutator segments are approaching the position in which they will be touching different brushes.

In Fig. 52, the armature has made a complete half turn.   No magnetism is being cut.   No current is being generated.   Both commutator segments are changing the brushes they are in contact with.
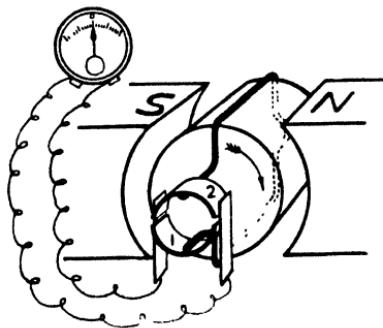
Fig. 52
Simple D.C. Dynamo.

In Fig. 53, the loop of wire is well into the magnetism again, current is being generated, and, naturally, the wire under the north pole is generating current in the same direction as it did before when the other arm of the loop was passing through its magnetism.   This means that segment 2 of the commutator must now be negative.   (Reference to the preceding figures will show that hitherto segment 2 has been positive.)
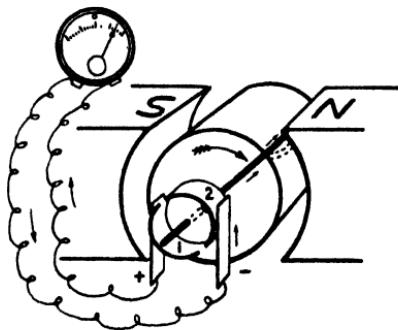
Fig. 53
Simple D.C. Dynamo.

This means that the right-hand brush is still negative.   It will now be clear that the function of the commutator is always to collect current from wires crossing the same part of the magnetic field and therefore having always the same direction of current flow.

The commutator is really quite a simple rotary switch. It will now be clear that every time a wire passes under a new pole, the current flowing in the wire changes its direction. It will be seen from these diagrams that every time a wire goes past a different pole, the commutator segment to which it is attached goes under a different brush. This is how the alternating current in the armature wires is led out of the brushes as a one-direction current.
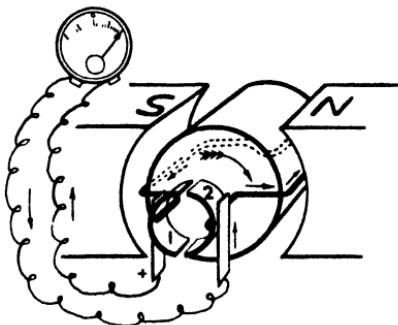
Fig. 54
Simple D.C. Dynamo.

In Figs. 54 and 55, the cycle is shown completing itself. The current rises to a maximum and falls away again. Owing to the switching action of the commutator the currents in the two halves of the cycle are in the same direction.
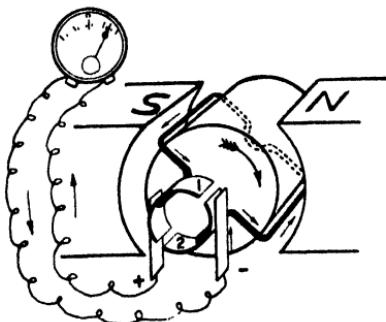
Fig. 55
Simple D.C. Dynamo.

The diagram in Fig. 56 shows the voltmeter readings at all the points in the rotation of our D.C. armature. It will be seen, if this diagram

*is compared with Fig. 41, that all that the commutator has done is to
transfer the reverse wave of half of the alternating current cycle to the
same direction as the first half of the wave.   If other coils are wound*
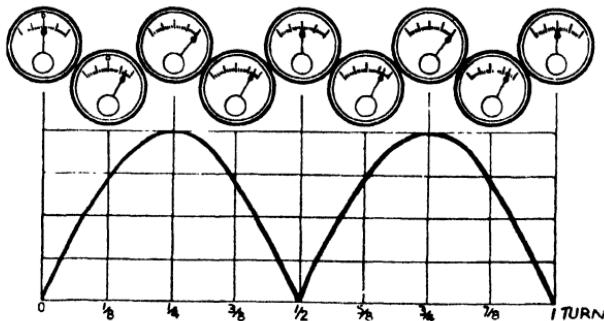
Fig. 56
Action of Commutator.

*on the armature so as to give currents like those shown in Fig. 41 but
turned into one direction currents by the commutator, then as all the
currents are going in the same direction these currents can be piled on
top of each other so as to give an almost smooth current.   Fig. 57
shows the effect of combining three such currents.   Instead of the single
current falling to zero, the voltage only ripples by 12% amounts.   By
adding more coils the ripples can be practically eliminated.   In
Fig. 57, the top ripply curve is the result of adding the three lower
currents on to each other.*
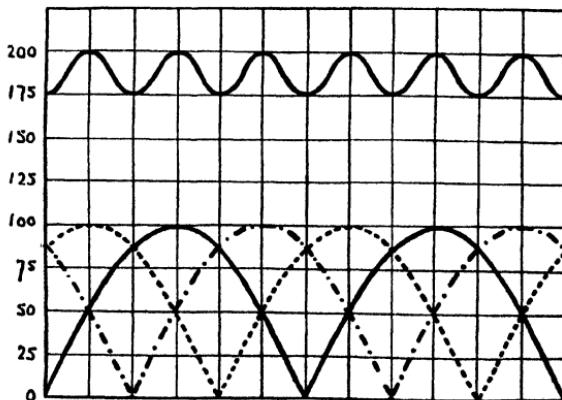
Fig. 57
Adding Commutated Currents Together.

CHAPTER 8. ELECTRICITY—USE.

And we must take the current when it serves,
Or lose our ventures.

SHAKESPEARE—Julius Cæsar—1599.

Electric Motors — Direct Current Motor Magnets — Direct Current Shunt
Motors — D.C. Series Motors — Compound Motors — Alternating Current
Motors—Synchronous Motors—Induction Motors—Self-Induction—Starting
of Motors — Power Factor—Power in a 3-Phase Circuit — Special Motors —
Robustness and Simplicity of Induction Motors—Protective Devices—Motor
Generators — Frequency Changers—The Measurement of Electricity—Electric Light.

The main text of this Chapter contains no references to the
illustrations, which carry their own explanations, printed in Italics.

ELECTRIC MOTORS.

It has been explained that an electric current is generated in a
wire if the wire is made to " cut " a " magnetic field," that is, if the
wire is made to pass across near to the pole of a magnet. The
reverse is also true. If a wire in a magnetic field, that is, near to a
magnet, has a current passed through it, it will try to move across
the face of the magnet pole. If we take a dynamo and pass a
current through its armature wires the armature will turn, because
the wires are trying to move across the magnetism.

DIRECT CURRENT MOTOR MAGNETS.

A direct current dynamo consists of an armature of iron round
which are wound coils of wire whose ends are attached to the
segments of the commutator. The armature is able to rotate in
bearings and is placed between the poles of a magnet. This magnet
is called the " field " magnet because it produces the magnetic field
in which the armature wires move. Coils consisting of many turns
of fine wire are used for energising the magnet and D.C. is used in
the coils so that the polarity of the magnets will always be the same.
On page 120 it was explained that the strength of a magnet was pro-
portional to the number of turns of wire in the coil and to the
amperes passing through the coil. This magnetising effect is
measured in " ampere-turns," that is the number of turns of wire

multiplied by the amperes passing through. It is more economical in electricity to use many turns of fine wire that will pass a small current than a few turns of thick wire that will pass a big current and will give a big heat loss (see page 126).

If we have a coil of 1,000 turns of wire that passes 1 ampere we have a coil with a magnetising power of 1,000 ampere-turns. If we have a coil of 100 turns of heavy wire which will pass 10 amperes we also have 1,000 ampere-turns. The heat loss in a circuit is proportional to the resistance multiplied by the square of the current. If in the first case the voltage is 100 volts then the resistance of the fine coil will be 100 ohms. If in the second case the voltage is also 100 volts then the resistance is 10 ohms. Now the heat loss in the fine coil will be proportional to $100 \times 1 \times 1 = 100$. The heat loss in the heavy coil is proportional to $10 \times 10 \times 10 = 1,000$. So that for the same magnetic effect the heat loss with the thick wire is 10 times as great as with the fine wire. (See Chapter 17).

DIRECT CURRENT SHUNT MOTORS.

If a D.C. dynamo is connected to a D.C. supply, current will flow round the magnet coils and energise the magnets. Current will also flow in the armature wires which are lying in the magnetic field. All these armature wires will try to move and they will all try to move in the same direction as far as effecting rotation of the armature is concerned. The armature will revolve. The greater the current flowing in the wires the greater will be the turning force on the armature. The direction in which the wires will move is found from a modification of Fleming's rule—pages 128 and 134—in which the left hand is used instead of the right. Right hand for dynamos. Left hand for motors. Point the middle finger of the left hand along the wire in the direction of the current flow when the first finger is pointing from north pole to south pole, then the thumb will point in the direction in which the wire will move. Now suppose that the current in the armature and in the magnetising coil are reversed in direction. It will be clear after a little turning of the left hand that as the north and south poles have changed places and as the current is flowing in the opposite way along the armature wires, the wires will still be trying to turn in the same direction as before. If it is desired to make the armature turn the other way either the current in the armature or the current in the magnet should be reversed but not both of them together. In practice reversal is always carried out by reversing the armature current. The polarity of the magnets is never interfered with.

On pages 128 and 134 Fleming's rule for finding the direction in which a current will flow when generated in the wires of an armature rotating in a magnetic field, was described. This rule employed the thumb and first two fingers of the right hand. For finding the direction in which a motor will rotate when current is fed into the armature, Fleming's rule is also used, but the LEFT hand is

Fig. 58.
Fleming's Rule (for motors.)

employed instead of the right hand. If the left hand be so held that the first or pointing finger points from north pole to south pole and the middle finger points along the wire in the direction of the current flow then the thumb will show the direction in which the wires will try to move.

Now let us return to our D.C. motor armature which has started to revolve. A very curious state of affairs is what we shall find if we investigate. By passing a current through the wires which are in a strong magnetic field we have started the armature rotating,

We know from our study of generators that if a loop of wire turns in a magnetic field a current will be generated in it. This is exactly what happens in the wires of the machine we are considering. All the wires in the rotating armature are generating a current in the opposite direction to the current that we are putting in. Fleming's right hand rule will confirm this. This opposition current is a voltage opposed to the supply pressure so that the effective voltage on the armature is the supply pressure minus the back generated voltage. It follows that as the armature speed increases and the back voltage consequently rises that less and less current will flow into the motor armature. Finally there will come a point where the back voltage nearly cancels the supply voltage and very little current will flow into the motor, too little to cause the speed to rise any more. A condition of equilibrium has been reached when the current taken in is just sufficient to overcome friction and air churning between the poles. Our dynamo machine is now running as a motor at full speed on no load. If any load is applied the motor will slow down a little, this at once reduces the back voltage that it is generating so that more supply current is able to flow in. This extra current causes a bigger turning force to operate on the armature and the motor settles down into a new condition of equilibrium at a slightly lower speed. Still more load will again reduce the speed with again a corresponding increase in current flow due to the reduction in back voltage. A motor of this sort is always trying to run at nearly its full speed. Even when fully loaded it will be only a very little below its light load speed, and at overload it will burn itself out by taking more current than the wires can carry in an endeavour to maintain its speed rather than slow right down.

A d.c. motor similar to a dynamo like the one that we have been describing is called a " shunt-wound " or just a " shunt " motor, because the current going to the magnet coil is shunted off the main supply. The only advantage that a D.C. shunt motor has over an alternating current induction motor—which will be described shortly—is that its speed can be easily and economically varied, whereas it is difficult, costly and not very efficient to vary the speed of a simple A.C. motor. Apart from this the D.C. motor is more complicated, more expensive and less reliable.

The way in which the speed of a D.C. Shunt Motor is varied is as follows : If less current is allowed to flow round the magnet coil the magnet strength will be lessened. In order to generate its back voltage the armature will have to rotate much faster. This " field regulation " or varying of the current which energises the magnet is the way in which the speed of these machines is controlled. As the magnetising current is only a small fraction of the whole current any heat dissipation in resistances is small and unimportant. A con-troller, which is just a kind of switch, is fitted in the wires leading

to the magnet coils so that more or less resistance can be switched in or out thus varying the magnetising current. (A resistance is just a coil of iron or nickel wire which does not pass electricity easily but which is sufficiently stout not to melt with the heat produced.)

D.C. SERIES MOTORS.

The direct current series wound motor is quite supreme for certain jobs. Cranes, lifts, railways, trams, all can be driven better by series motors than by any other type In the series motor the magnet coil instead of being a many-turned coil of fine wire is a thick coil of comparatively few turns. Instead of a part of the current being shunted through it, the whole of the armature current goes through the magnet coil as well. This means that when the armature current increases the magnetising current increases also, and when the armature current falls the magnetising current falls as well. This produces a very useful and interesting effect. Assume a series motor to be running at a fairly high speed on a light load. Now when the load increases the motor will slow down and generate less back voltage. This enables the supply voltage to send in a bigger current and this bigger current goes through not only the armature but the magnet coils as well. The armature current is trying to speed the motor up but there is now no necessity because the increased magnetising current has so increased the magnetism that the requisite back voltage can be generated at the reduced speed. This means that a series motor will carry an increased load at a lower speed. If still more load is applied the speed again drops, the back voltage therefore drops and this allows more current to flow in from the supply and this increases the turning force on the armature and at the same time increases the magnetism so that it is not necessary for the armature to go so fast to generate the requisite back voltage. A shunt motor will burn itself out in an endeavour to take a big overload at nearly its light load speed. A series motor will just slow down and take the extra load at a proportionately lower speed. When a fully loaded tramcar comes to a hill the series motors driving it just slow down and quietly take the extra load and when the level comes they just speed up again. If a tram was fitted with shunt motors they would try to run at almost constant speed uphill or downhill and would burn out at the first steep hill in a vain endeavour to maintain speed. A series motor on no load runs away. When load comes off the speed goes up, this increases the back voltage which decreases the current taken from the supply and this means that the magnetising current is less so that the armature has to speed up still more in order to generate the back voltage. This process goes on repeating itself until the motor is running so fast that the armature flies to pieces. Generally, series motors are under the control of a man in a crane, lift, tram or train and he can

prevent the speed rising dangerously high.   But where series motors are used without human supervision other means for preventing their running away must be used.

COMPOUND MOTORS.

If a motor has most of its magnetising current provided by a heavy coil of wire arranged in series with the armature and a small coil shunted off the main supply it will have all the good properties of taking heavy loads at slow speeds that a series motor has and at the same time the magnetism that the shunt coil provides prevents the speed rising to a dangerous height.   For different purposes the proportion of the shunt and series magnetising coils can be varied to give the motor more or less series characteristics at the gain or expense of the shunt characteristics.   A motor provided with both series and shunt coils is called a compound motor.

ALTERNATING CURRENT MOTORS.

It has just been explained how a direct current dynamo, if supplied with current, will run as a motor.   In fact apart from certain special applications, the motor and the dynamo are to all intents and purposes identical.   Now the same thing does not quite hold good in the case of alternating current.   While an a.c. generator can run under certain special conditions as a motor, most a.c. motors are much simpler and more robust than any generator.   This is one of the important reasons why alternating current has displaced direct current.

SYNCHRONOUS MOTORS.

If an alternating current generator is supplied with the same sort of current, that is same voltage, same frequency, same number of phases, as it generates as a generator it will run as a motor provided that it is run up to speed first.   This speed is the speed at which it would be running as a generator and is called the synchronous speed.   The machine will not start itself.   This is not easy to understand.   When the machine is stationary d.c. is energising the magnets and creating a steady magnetic field.   If a.c. is supplied to the armature all the wires on it will try to move first one way and then the other as the current alternates and no rotation will take place.   Consider one particular wire opposite one particular pole. The pole has a constant polarity, but the wire is getting current first one way and then another and from Fleming's rule we shall see that the wire will try to swing to and fro.   If the frequency of the supply is 50 it will be quite impossible for a heavy armature to swing to and fro 50 times a second but it may be able to make a low humming noise.

If the machine has been run up to synchronous speed quite a different condition appears. The wire that we have been considering will be under a north pole while it was getting current from left to right, say. Now the current dies down to nothing and at this moment the wire passes between two poles and as the current starts to flow from right to left the magnetic field has also changed and the wire is under a south pole. By Fleming's rule we see that under these conditions there will be a continuous turning force in a constant single direction acting on the wire and in fact on all the wires in the armature and the machine will run as a motor at synchronous speed. Any load that comes on will momentarily try to slow the armature down but this will at once cause a tremendous cutting of magnetism and a corresponding tremendous pull on the armature. If such a big load comes on however as to pull the armature " out of step " then there will be no turning force on the armature, merely a series of pulls first in one direction and then in the other. If a synchronous motor gets such a big load as to pull it out of step then it at once stops as there is no longer any continuous one-direction turning force.

Synchronous motors are now made that are self-starting. They are provided with a few induction motor windings. Synchronous motors are only used by us for " power factor " correction (see page 169).

INDUCTION MOTORS.

The alternating current induction motor is quite unequalled as a simple robust, reliable machine for driving plant. Although it works on the principle of wires exerting a turning force when a current passes through them if they are in a magnetic field, the induction motor is quite different from a generator or synchronous motor. In a d.c. motor or in a synchronous a.c. motor the current is supplied to the armature wires direct from the supply. In the induction motor the current in the armature wires is " induced " by magnetism in the magnet or stator of the machine and the armature has no connection at all with the mains.

Imagine three separate bar magnets equally spaced round a circle with one pole or end pointing inwards to the centre and the other pointing outwards. In the space inside the inner magnet poles an armature is mounted. On each of the magnets is wound a coil of wire. Each coil of wire is connected to one of the three phases of the three phase supply. We will assume that one magnet is at 12 o'clock, one at 4 o'clock and the other at 8 o'clock. Now when the current is greatest in the 12 o'clock coil and in such a direction that this magnet shows a north pole to the armature then the currents in the other two coils are each equal to half the current in

the first coil and are in the opposite direction. So that the other two poles pointing to the armature will be south. As the current alternates the current in the 12 coil will drop slightly while the current in the 4 coil will drop to zero and its pole will have no magnetism, but the other two will be equal and opposite. That is to say that pole 12 is still north and getting weaker while pole 8 is south and getting stronger and pole 4 has become zero from having been south. As the current in coil 12 continues to fall the current in 8 rises and the current in 4 rises also in the other direction so that pole 4 is now a north pole. As pole 4 continues to increase in strength as a north pole, pole 12 gets weaker and weaker until its current becomes zero and it loses its magnetism. If we go on with a detailed consideration of the rise and fall of the different phase currents we shall see that each pole in turn is becoming a north pole going the round of the poles in a clockwise direction. The 12 pole started full north when the 4 pole was half south. Then the 12 pole was still north when the 4 pole was zero. Then the 12 pole and the 4 pole were each half strength north. Finally when the 12 pole lost its magnetism the 4 pole was approaching full north strength. We find that the magnetism goes round the inside of the magnets with a speed equal to the frequency of the supply.

It would be wasteful to use an arrangement such as that just described with half the magnet poles sticking outwards to where they could do no good. If we had three horseshoe magnets, one for each phase, spaced round so that the other pole of the 12 magnet was at 6 o'clock, great magnetic benefit would result. We saw that when magnet 12 was at full north strength poles 4 and 8 were at half south strength. The new pole at 6 will clearly be a full strength south pole in between the two half strength south poles. And the other new poles belonging to the 4 and 8 magnets will be at 2 and 10 and will be half strength north poles on either side of the full strength north pole.

In practice it has been found better to wind these magnetising coils in slots on a continuous ring. Each phase coil is made to overlap the next and a much smoother magnetic rotation is obtained. The magnet wound in this way looks exactly like an armature. It is usually called the stator because it does not revolve but stays still.

When a stator such as has been described is supplied with A.C. a magnetic field whizzes round inside it at a speed equal to the frequency divided by the number of pairs of poles in each phase— not the total number of poles.

Inside the stator is an iron drum or armature, which in an induction motor is always called the rotor because it rotates. In

slots on the face of the rotor are a number of heavy copper wires o bars all connected to each other at their ends by copper or brass rings.   These wires are not connected to any supply.   As the magnetic field rotates it cuts these wires and so generates a current in them and this current just flows round and round the bars and end rings.   But we know that when current flows in wires which are in a magnetic field the wires try to move.   So the rotor starts to revolve.   The faster it runs the slower is the magnetism cutting the wires and therefore the less is the current being generated in the rotor and therefore the less is the turning force tending to accelerate the rotor.   The rotor will settle down at some speed which must be less than synchronous speed.   Because as soon as synchronous speed is approached the current induced in the rotor bars drops and the turning force disappears.   When load comes on the rotor it slows down a bit.   This causes the magnetic field to cut the rotor bars faster and so generate more current which in turn drives the rotor faster.

SELF-INDUCTION.

At first sight it would seem that the amount of current taken by the stator from the mains would always be the same and would have to be sufficient to drive the motor on full load.   Actually this is not the case at all and the current is automatically kept down to just the amount needed for the power requirements at any moment by an effect called " self-induction," which is rather difficult to explain.   When an alternating current flows through a coil wound round an iron core it builds up waves of magnetism, and as the current in the coil rises and falls so the magnetism waxes and wanes.   When the magnetism waxes it can be looked upon as swelling out from the iron and when it wanes it can be looked upon as collapsing back on to the iron.   In either case it cuts the wire coil and in doing so it generates or induces a current in the magnetising coil which is exactly similar to the back voltage generated by a D.C. motor.   This " self-induced " current prevents any appreciable current flowing in a coil which is associated with a magnet unless some of the magnetism is used up by some outside interference.

Now in an induction motor on load something outside the magnetising coil and its iron core does interfere, namely the wires on the rotor.   The currents that are induced in the rotor bars by the rotating magnetism use up some of the magnetism so that there is less available for self-induction.   There is less back-induced current so that more current can flow from the main.   This causes a greater magnetic intensity in the rotating magnetic field with a corresponding increased turning force on the rotor bars.   If load comes off the

rotor it will speed up a little and this will mean that it is cutting the magnetism slower and the currents induced in the rotor bars are less, therefore there is less magnetism used up in inducing rotor currents and there is more left for self-induction, with a result that there is a greater back-induced current and less current is taken from the main. Self induction is an exact parallel to the back voltage generated by a d.c. motor. An example of self induction with which many may be familiar, especially if they are radio enthusiasts, is the case of a transformer. A transformer consists of two separate coils of wire wound on an iron core. The self induction is so perfect that if no current is taken from one coil on the transformer, called the secondary coil, then no current flows into the other coil, called the primary coil, although it is directly connected to the supply main, because the self-induction current exactly counterbalances the supply current.

The direction of rotation of an induction motor is the same as that of the rotating magnetic field. In order to change the direction of rotation all that need be done is to reverse the wires attached to two of the phase windings of the stator.

THE INDUCTION MOTOR.

The induction motor driven by two or three phase alternating current is of the utmost importance because it is the simplest and most robust form of power machine. It operates by producing in a fixed magnet or stator a revolving field of magnetism, which induces currents in the bars of the rotor. These currents cause a turning force to act on the rotor because they are flowing in wires which are lying in a magnetic field.

Figure 60 shows diagramatically a stator which has six poles projecting inwards from it. Round each pair of opposite poles is wound a coil from one particular phase so that the machine has one pair of poles per phase. In figure 60 the coils are shown as plain, dotted and dot and dash to correspond with the current curves on the diagram of a three phase alternating current shown in Figure 59 which is the same as the diagram in Figure 41. Now the currents in the three phases shown as curves in Figure 59 are those that occur in one complete cycle or, in the case of a two pole machine, in one complete revolution of the armature. The figures shown on the up and

down scale as + or − are the voltages, while the figures along the horizontal scale are the positions reached, compared to the hours on a clock face, by the armature during one turn.
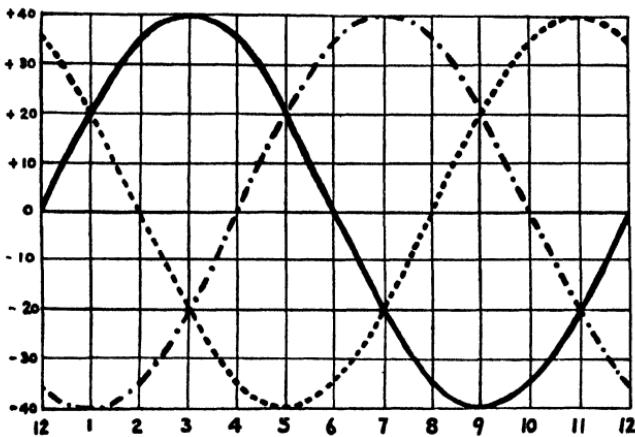
Fig. 59
Three Phase Alternating Current.
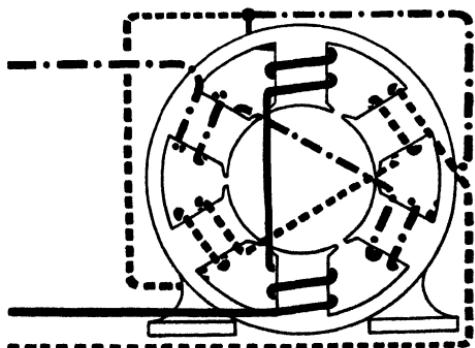
Fig. 60
Induction Motor Magnet Coils.

Figures 61 to 67 are simplified copies of the stator shown in Fig. 60, but with most of the wiring omitted for simplicity. The magnetism has been shown as lines crossing the central space in a direction from north to south. They represent the magnetic condition in the space inside the poles at the seven positions 12 to 6, inclusive, of the current curve, Fig. 59. Fig. 61 is the state of affairs at position 12 in Fig. 59. The plain phase is at zero volts, therefore the poles at 12 and 6 o'clock, which are energised by this phase, will have no magnetism. The dotted phase has a voltage of + 35 and reference to Fig. 60 will show us that the dotted phase gets its supply from the 2 o'clock end of its coil, and Fleming's rule tells us, therefore, that the pole end projecting inwards will be north. The dot and dash phase has a voltage of − 35, as can be seen from the curve in Fig. 59, and Fig. 60 shows that this phase commences its coil at the left-hand side of the 10 o'clock pole. Fleming's rule shows us that the inner end of the 10 o'clock pole will be south. Fleming's rule also tells us that the other poles energised by these two phases will be of the opposite polarity. The magnetism, therefore, is arranged horizontally.
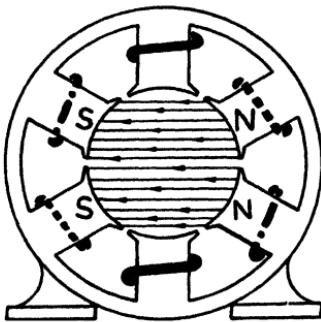
Fig. 61
Induction Motor Rotating Magnetic Field.

Fig. 62 shows the state of affairs in our stator when the conditions of current in the phases are as shown at position 1 in Fig. 59. The dot and dash phase has still the same direction of current but the voltage is now 40. Pole 10 is therefore still south, and pole 4 is still north, but the magnetism they are causing is a little stronger than in Fig. 61. The dotted phase has a smaller current but still in the same direction as in the previous case. Pole 2 is therefore still north and pole 8 is still south but the magnetism is less. The plain phase has now got a positive voltage of 20, and Fig. 60 shows us the direction in which this current will flow through the magnet coils, and Fleming's rule tells us that

pole 12 will be south and pole 6 north. The magnetism has turned in a clockwise direction a distance equal to one hour on the clock.
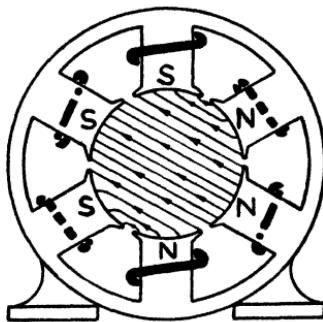
Fig. 62
Rotating Field.

In Fig. 63, the conditions are as shown on Fig. 59 at position 2. The dotted phase has dropped to zero voltage so that the two poles, 2 and 8, energised by this phase, have no magnetism. Both the other phases have their currents still in the same direction as previously, only the dot and dash phase has dropped from its highest voltage to 35 volts, and the plain phase has risen to 35 volts. The result of this is that the magnetism has again turned in a clockwise direction by an amount equal to one hour.
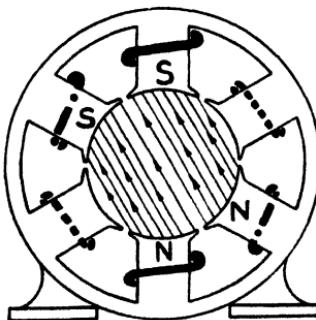
Fig. 63
Rotating Field.

Figs. 64, 65, 66 and 67 show the magnetic condition at the points in the current diagram corresponding to points 3, 4, 5 and 6. They can be followed quite readily by applying Fleming's rule to the coils in

Fig. 60 according to the current conditions shown in Fig. 59.
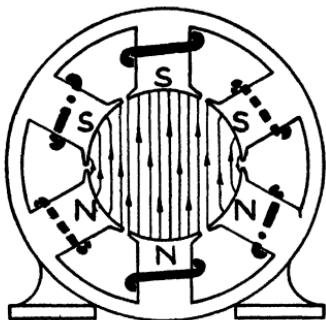
Fig. 64
Rotating Field.
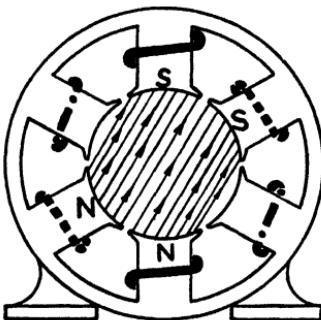
Fig. 65
Rotating Field.
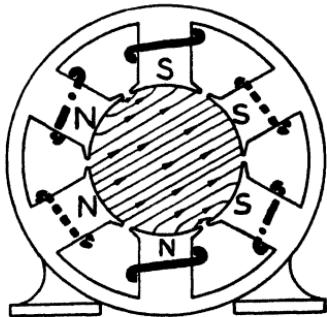
Fig. 66
Rotating Field.
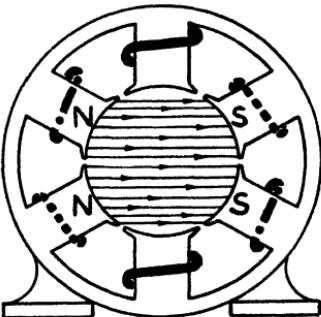
Fig. 67
Rotating Field.

It will be seen that the magnetism rotates once for each cycle. Actually, the correct rule is that the speed of rotating is the frequency divided by the number of pairs of poles in each phase. The magnet stator shown in the diagram is not a six-pole stator, but a two-pole stator. Each phase has one pair of poles. The wires on the armature or rotor are cut by this rotating magnetism, and currents are generated in them. This causes them to try to turn, and the armature revolves. In actual motors the windings are put into slots, and one phase winding often overlaps the next.

STARTING OF MOTORS.

It is hoped that after the description of the working of both a.c. and d.c. motors it is quite clear that the automatic regulation of the current flow into the motor to suit the varying conditions of load is due simply to the generation or to the induction of a back voltage. When the motor is stationary there can be no back voltage in a d.c. machine, and in the a.c. machine the whole of the magnetism is used in generating or inducing rotor currents and there is no back self-induction. At the moment of starting from rest therefore there will be an enormous rush of current. This great rush is undesirable for several reasons. It may damage the motor or the wires leading to it. It may be too much for the supply generator to deal with especially if several motors were started simultaneously. Some means therefore must be found to limit this rush of current at starting. D.C. motors are started by means of a set of resistances which limit the amount of current that can flow. A resistance is a coil of wire made of some metal which does not conduct electricity well. Quite a heavy wire will then carry a comparatively small current and the heat generated will not melt the wire. If a copper wire were used as a resistance it would have to be so thin to offer any appreciable resistance that it would melt with the heat caused by the passage of the current. A d.c. starter is just a switch that has about 6 or 8 positions, each position putting a different resistance into the circuit. The first position has the most resistance so that the current at the instant of starting may not be too great. The next position has rather less resistance because as soon as the armature is turning there will be some small back voltage and there will in consequence be less need to limit the current. As the speed rises and consequently the back voltage, the resistances can be successively cut out until the supply is directly connected to the motor.

Small a.c. motors are usually made sufficiently robust to stand up to the passage of the heavy starting current and because such motors are small their starting currents will not upset the generating system. As however the starting current may well be several times greater than the full load current complications arise with the motor protection devices (see section later on in this chapter). Small motors are protected from overload by fuses—lengths of thin wire which melt if excessive current passes—and were these made heavy enough to bear the starting current they would not be sensitive enough to protect the motor against overload. While if they were made thin enough to be adequate running protection they would melt every time an attempt was made to start the motor. In small motors the starting switch usually takes the form of a simple switch which bypasses the fuses during starting. The motor is started by

the switch handle being moved one way, in a direction in which it will not stay without being held in position.   As soon as the motor has reached normal speed, the switch handle is thrown over to the running position where the fuses are in circuit and the protection coils (see later section) hold the switch in position.

Large a.c. motors cannot be started in this way.   One of the best ways of preventing an excessive rush of current at starting a large induction motor is to wind the rotor in such a way that the induced currents can be led out by slip rings and passed through resistances outside the motor.   This makes the motor much more complicated and expensive.   Other methods are those that reduce the voltage of the supply during starting.   The simplest of these is that known as the star-delta system.   If the three different phase windings each have one end connected to one of the supply wires and their other ends are connected to a common point it has already been explained that no current flows at the connecting point as the voltage there is always zero.   This type of connection is called star. Another way of connecting the stator coils is to connect one end of one phase coil on to one end of the next phase coil and to connect a supply wire to the junction points between the phases.   This is called delta connection (delta is the Greek capital letter D and is an equal sided triangle).   Owing to the interference, in delta connection, of the voltage in one phase with that in another, the voltage across each phase coil when connected in star is only 58% of that in delta connection.   If we have a 440 volt supply we get 440 volts across each phase if we connect them in delta, but only 250 volts if we connect them in star.   A simple change over switch enables the motor to be started on star and changed over to delta when running.   The voltages of star and delta connections are dealt with in Chapter 17.   As the explanation involves a certain amount of mathematics it is not included here.

The other common method of reducing the voltage of the starting current is by means of what is called an auto-transformer. If a coil of wire through which a current is passing is wound round an iron core preferably ring shaped, as the current alternates the magnetism surrounding the core also alternates and can be thought of as breathing in and out.   This magnetism cuts the wires of the coil and induces a strong back voltage in the coil.   From one end of the coil and from a point some distance along the coil wires are led off thus tapping a part of this self-induced current and using it as the starting current.   The voltage is proportional to the amount of the coil that is tapped.   When the motor has got up to speed the supply current is switched on to the motor direct.

POWER FACTOR.

When an alternating current flows through a coil which is

associated with iron and has a magnetic field to build up, this magnetic field causes self-induction of a back current in the coil and this causes the current in the coil to flow more slowly, in fact the quantity of current in amperes lags behind the voltage. It is not easy to explain this but an idea of the condition may be obtained by imagining something quite different which shows the same property. Consider the condition of a tennis ball during a rally. When the ball strikes the player's racket it is travelling in the opposite direction to the racket and although it is receiving a great impulse from the racket it does not instantaneously move in the new direction but first flattens very considerably and does not reach its full speed on its return journey until after it has received the chief impulse from the racket. The players are exerting their pressure on the ball definitely in advance of the ball's movement. The players' rackets are alternating and so is the ball but the ball is lagging behind the racket impulses. In just the same way the current lags behind the voltage impulse in an alternating current circuit that is such that it causes much self-induction. This gives rise to a curious state of affairs when the volts drop to zero just before changing direction. Though there are no volts the amperes will be following along a bit behind and will not be zero. So that for a moment we have amperes without volts.

The power of an electric current is measured in watts which are volts multiplied by amperes. If the volts are zero the watts must be zero too, however large the amperes may be. So we seem to be having a current which has no power but which has amperes and which therefore can have a heating effect and consequently a heating loss. The percentage of the current that is power-producing compared with the total current including the "wattless" current is called the power factor. If the power factor is low it means that there is a lot of wattless current and that all the cables and probably the generator are not carrying nearly the full load that they could. They may be being uselessly heated up by the wattless current. A power factor of ·85 means that 85% of the amperes that are flowing in the circuit are useful "powerful" amperes while 15% are wattless. Many machines, particularly centrifugal machines are driven by special motors whose other essential characteristics cause the power factor to be bad under certain conditions. We put up with this bad power factor because we get other compensations. We can and do correct very bad power factor circuits by using large synchronous motors for driving some large constant machine. When a synchronous motor is given an excessive magnetising current in its magnet coils the current taken by its stator can be made to "lead" instead of "lag." That is to say its wattless current is in front of instead of behind the voltage wave. It is not necessary to try to explain why this effect takes place. The whole conception of

power factor, especially a leading one is difficult to comprehend. All we need to know is that a leading power factor can be made to counteract a lagging one and a feeder from the power house that is feeding a lot of motors with bad lagging power factors can be made much better by feeding also an over excited synchronous motor. One point about power factor needs emphasising, namely that a power factor of .7 lag does not mean that 30% of the power is being wasted. Nothing of the kind. It merely means that 30% of the amperes flowing in the circuit are wattless and cannot give power but can cause a heat loss. (See Chapter 17).

POWER IN A 3–PHASE CIRCUIT.

On page 124 it has been explained that electrical power is measured in Watts, that is the volts multiplied by the amperes flowing in the circuit. Now the amperes flowing in an alternating current circuit may not be the true, power-producing amperes. It depends on the power factor. So that for finding the power in an A.C. circuit the amperes must be multiplied by the Power Factor.

What of the volts ? The real voltage in each phase is the volts in star connection. But the practical voltage that we measure by putting a voltmeter across two wires of the circuit is the delta voltage and is the difference of potential in the wires. The negative voltage in one phase is added to the positive voltage in the other. The true star voltage is $57\frac{3}{4}$% of the delta voltage measured across two line wires. So we must take $57\frac{3}{4}$% of the apparent voltage.

As there are three phases each giving power we must multiply our watts by three. So that the power in a three phase circuit in watts is :—

$3 \times$ (Amperes $\times$ Power Factor) $\times$ (Apparent Voltage $\times \frac{57.75}{100}$)

which is equal to :—$1 \cdot 732$ A $\times$ PF $\times$ V.

(The voltages of star and delta are discussed in Chapter 17).

SPECIAL MOTORS.

Apart from synchronous motors that are expensive and somewhat complicated, the only special motors that we use in any number are special induction motors for driving centrifugal machines. These motors have very little full speed running to do. Their principal task is to accelerate the machine which is stopped very soon after it has reached full speed. Many machine motors have to do 20 starts an hour and the starting takes about three quarters of a minute. In order that the switch gear shall not be unduly complicated these

motors are switched directly on to the supply and the great rush of current that would otherwise occur is reduced by making the resistance of the conductor bars in the rotor abnormally high. This keeps down the currents induced in the rotor and leaves plenty of magnetism for self induction so that the back induced current is fairly high thus keeping the supply demand within reasonable limits. This extra resistance in the rotor makes the machine inefficient at full speed and causes a low power factor.

The motors on the Roberts centrifugal machines are arranged with their magnet windings in such a way that by changing over a switch they can either be 4 pole windings or 8 pole windings. When starting they are switched on to 8 pole. This makes the rotating magnetic field rotate at half the normal speed so that only half the normal starting current is induced in the rotor and half the normal starting current drawn from the supply. A few seconds after starting, the switch changes over automatically and makes the magnet windings into 4 pole windings when the magnetic field will double its speed of rotation. Normal acceleration will now take place without the tremendous current rush that would have occurred had the motor started as a 4 pole machine. When it is desired to stop one of these machines, instead of switching off the supply, the connections are changed back to the 8 pole position with the result that the rotor wires are running nearly twice as fast as the magnetic field. This causes the induction in the rotor of a big current in the reverse direction which slows the rotor down rapidly. These big rotor currents induce corresponding reverse currents in the stator windings which are in opposition to the supply, which means that the motor is generating a return current to the mains. This is called regenerative braking because the energy of the rotating machine is made to regenerate a current into the main.

ROBUSTNESS AND SIMPLICITY OF INDUCTION MOTORS.

An induction motor is an exceedingly simple and robust machine. This particularly applies to the rotor. Except for those few motors which are designed for starting by means of the insertion of resistance into the rotor circuit, there are no real " windings " on the rotor. The rotor wires consist of stout copper bars riveted and brazed into stout brass end rings. Such a rotor is called a " squirrel cage " rotor.

One important point in the construction of motors which applies equally to a.c. and d.c. machines concerns the iron part of the rotor which carries in its slots the windings or bars. In addition to the copper conductors which cut the magnetism, the iron part of the rotor does so also and currents will be generated or induced in the iron which would cause what are called eddy currents which would

cause wasteful heating, if steps were not taken to minimise them.
In order to prevent these eddy currents flowing in the iron parts,
the iron armature core or rotor is made up of thin discs or lamin-
ations which are varnished so as to insulate one from the other so
that the eddy current can only flow within the thickness of one
sheet. Such a sheet cuts so little magnetism in its own thickness
that the voltage produced is so small that a negligible current flows.

PROTECTIVE DEVICES.

An electric motor is a willing horse. It will try to take any
load that is put upon it. But if too great a load is applied the
current flowing will become so great that considerable heating may
take place and this may be so great that the insulation would burn,
soldered joints at the commutator of d.c. machines might melt and
perhaps even the copper wires might melt. The simplest device for
protecting an electric machine against excessive current is the fuse.
A fuse is a piece of wire placed in the circuit and made of some
metal which melts easily. Fuses are generally made of tin or of
tinned copper. A fuse can be made of such a thickness that it will
melt and break the circuit when the current reaches a certain pre-
arranged value. Fuses would seem at first thought to be sound and
simple devices, but actually they are not at all perfect. They must
contain some lag and the lag is variable. It has been found that
safety devices should be provided with qualities that the fuse does
not quite possess. The breaking current should be quite definite
and the lag should also be quite definite and both should be readily
adjustable. The safety device that is universally used is the overload
release coil. This is a small magnet coil through which the current
flowing to the machine is passed and whose current energises a
magnet which holds a catch which retains the machine switch in
the " on " position. If the current reaches a certain value the over-
load coil operates the catch and allows the switch to open. A time
lag usually consisting of a piston working in a cylinder full of oil is
attached to the overload release catch.

Another precaution that has to be taken is to safeguard all
plant after an interruption of the main supply. If the main supply
fails, all the motors connected to it stop. When the supply is
restored all the motors would start up simultaneously through their
running switches if there were there no safeguard, and none of them
would be started properly by star-delta, auto-transformer or other
means. This would not only damage the motors but would cause such
a rush of current that the supply could not cope with it. The device
used to guard against this danger is the low volt magnet, which is
just the same as the overload coil in that it is a small magnet coil which
is connected across the supply. When there is a reasonable voltage
the coil energises its magnet sufficiently to cause it to hold in the

catch retaining the motor switch in the running position. If the current fails or the voltage drops materially the magnet releases the catch and the switch opens. This means that if there is any interruption in the supply all the motor switches will have opened and no motor will start up of its own accord after the supply is restored.

MOTOR GENERATORS.

In many parts of the refinery we want direct current. All our cranes use d.c. motors. Machines that require nicely graduated speed control use d.c. motors. We have for example 20 d.c. motors driving printing machines. Direct current is more satisfactory for lighting than a.c. In order to get our d.c. we couple a d.c. generator to a large a.c. motor ; which is in effect converting a.c. into d.c.. It would seem better to generate d.c. direct from a steam turbine or engine driving a d.c. generator. We did this for many years but we now think that it is more efficient to generate all the power we want as a.c. in one large turbo-alternator set. A small steam engine or turbine is very wasteful. A d.c. dynamo does not work well at very high speeds and is best driven from a turbine through gears. Reciprocating engines are not very satisfactory on the modern very high steam temperatures. So that there are a number of good arguments in favour of generating our d.c. current by means of a motor driving a generator or " motor-generator " as it is called.

FREQUENCY CHANGERS.

In the section on page 143 dealing with alternators it was explained that alternators for a given frequency could only be run at certain definite speeds depending on the number of poles in the machine. Now an induction motor will only run at a certain speed dependent on the supply frequency and the number of poles in the motor stator and this speed is less than the synchronous or alternator speed, by from 2% in the case of very large motors to 10% in the case of quite small motors. Now it happens that we want speeds of 1,200 and 1,600 r.p.m. for a number of our centrifugal machines. We also want to be able to run these machines quite slowly for ploughing out the sugar. These special speeds are obtained by providing special current supplies at the necessary frequencies, namely, 42·8 cycles for 1,200 r.p.m., 57 cycles for 1,600 r.p.m. and 5 cycles for the ploughing. The machines, called frequency changers, for producing these special frequencies are simply motor generators of particular characteristics. A 50 cycle motor with sufficient poles to run at a suitable speed is connected to and drives a generator with the correct number of poles to generate the desired frequency at the speed in question. For example, to generate 57 cycle current we

use a 50 cycle motor having 14 poles and therefore running at 429 r.p.m. and a generator having 16 poles; and to generate 42·8 cycle current we use also a 50 cycle motor with 14 poles running at 429 r.p.m. but driving a generator with 12 poles.

THE MEASUREMENT OF ELECTRICITY.

The instruments which measure volts, amperes and watts are of many different types and will not be described in any detail. They all work on roughly the same principle. A very tiny electric motor has its armature restrained from turning by a hair spring and when current flows in the armature it will turn until the turning force is balanced by the restraining force of the spring. Attached to the armature is a pointer which indicates on a scale. A voltmeter is connected in such a way that the current from the mains goes direct into the armature of the instrument through a high resistance. The greater the voltage the greater will be the current flowing in the armature of the instrument and the greater amount will the armature turn before the spring stops it. An ammeter is a similar instrument only the armature of the instrument is connected across a very low resistance, called a shunt, through which the current is flowing. The greater the current the greater will be the voltage drop across this shunt resistance and the more current will flow in the armature of the instrument. In the case of a wattmeter, the current taken from across a shunt is applied to the magnet of the instrument while the rotor is supplied from the mains like a voltmeter. In this way both volts and amperes are measured at the same time.

ELECTRIC LIGHT.

An electric light bulb is just a very thin wire of such a resistance that it will allow just the right current to flow to heat it up to white heat. If the white hot wire were exposed to the air it would quickly oxidise and burn, so it is enclosed in a glass bulb from which all the air has been removed and which is left at either a high vacuum or is filled with an inert gas. There are four kinds of lamp bulb. The "carbon" lamp has a wire or "filament" of compressed carbon and gives very little light for the current it uses. It uses 4 watts for every candle power, but it is very strong and stands rough handling. It is used for hand leads and in places where it may get knocked about. The next most efficient is the metal filament vacuum lamp which consists of a fine wire of one of the rare metals such as osmium, tantalum or tungsten in a bulb from which all the air has been removed. These lamps only require 1 watt to give one candle power. They are fairly robust and have the great advantage that as they get old their light does not fail. Next in efficiency come the gas-filled metal filament lamps. These contain a very

closely wound fine spiral of tungsten wire and the bulb is filled with an inert gas such as nitrogen or argon. They give 2 candle power for each watt of current taken but they are fragile and as they get old their efficiency falls off. The most efficient are the mercury vapour lamps. These contain a small pool of mercury, part of which is boiled off to form vapour. When the bulb is filled with vapour of a sufficient pressure an electric discharge takes place across it and the gas glows brightly. This type of lamp is the most efficient and gives about 6 candle power per watt of current used, but the bulbs have only about half the life of metal filament lamps and the light they give is of an unearthly green.

CHAPTER 9. PUMPS.

" You can draw water out of a water-well,"
said the Hatter, " so I should think you could
draw treacle out of a treacle-well—eh, stupid ? "

CARROLL—Alice's Adventures in Wonderland—1865.

The main text of this chapter contains no reference to the illustra-
tions, which carry their own explanations, printed in italics.

Pumps of various kinds are required all over the refinery.   At
each of our refineries we have about 200 pumps.   In most places
the purpose of the pump is quite obvious.   While there are a great
variety of kinds and designs of pumps there are two broad kinds of
outstanding importance—centrifugal pumps and piston or plunger
pumps.

CENTRIFUGAL PUMPS FOR LIQUIDS.

A centrifugal pump is cheap, occupies very little space, runs for
long periods with little attention and possesses the other good and
useful qualities which are about to be described.   It is not so
efficient as a reciprocating (piston or plunger) pump, that is to say
it uses more power for the same amount of liquid pumped.   It is
able to damage sugar liquors under certain conditions—the heavier
the liquor the lower the efficiency of the centrifugal pump and the
greater the damage it can do to the liquor.

Centrifugal force is the force that makes a thing fly outwards
when it is swung round fast.   Centrifugal force makes a motor car
skid when it goes round a corner too fast.   It is to counteract
centrifugal force that a cyclist leans inwards when cornering.
Centrifugal force prevents you from standing on the joywheel at
Blackpool or Southend.   David killed Goliath by using centrifugal

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force when he swung his sling and released his stone. Centrifugal force is due simply to the natural desire of all moving things to move in a straight line and if made to move in a curve their centrifugal force has to be overcome. (See Chapter 17 for an explanation of centrifugal force.)

A centrifugal pump is simply a machine which whizzes the liquid round quickly by means of vanes on a revolving disc. The liquid flies out against the casing with considerable force and is therefore under a pressure so that it will readily flow out of an opening in the casing if one is provided. As the vanes throw the liquid outwards, thereby making the pressure which forces the liquid out of the pump outlet, it follows that there must be an emptiness or vacuum in the middle of the pump disc. The inlet or suction opening is formed in that part of the casing near the centre of the impeller, as the disc carrying the vanes is called. The best shapes for the impeller and its vanes as well as the casing and outlet have been found by experience.

The impellers of some pumps consist of a single disc with vanes on one or both sides. In other designs of pump the impeller is made up of two discs with vanes between them and holes in one or both discs at their centres to allow the liquid to flow into the vanes.

When a centrifugal pump is running empty it acts on air in the same way as on liquid, namely the air is thrown outwards by the vanes. As the air is so much lighter than liquid the suction produced at the centre of the impeller is very small. When the pump is full of liquid quite a high vacuum is produced at the suction. A centrifugal pump is therefore always so placed that the liquid it is to pump can run into it. If this cannot be done it will be necessary to fill the pump with liquid or to " prime " it before it can start pumping.

PRESSURE FROM CENTRIFUGAL PUMPS.

A little thought will make clear the fact that the pressure which a centrifugal pump can give depends on the centrifugal force imparted to the liquid—that is to say on the diameter and speed of the impeller. The larger the impeller diameter the greater the centrifugal force, so that the pressure is higher. The faster the impeller is rotating the greater is the centrifugal force and the higher the pressure. Whether the liquid can get out of the pump casing or not has no effect on the centrifugal force. This means that there is a certain pressure that each individual centrifugal pump can give and nothing short of running it faster or altering the impeller can increase the pressure.

This automatic limitation of pressure is a very useful property.

It enables a valve on, for example, the pan floor to be shut against a pump in, for example, the liquor room without causing any mechanical damage. When the valve is shut against the pump, although no liquid is being pumped, the pump is exerting centrifugal force on the liquid in the impeller and therefore causing a certain pressure in the pump casing, but the liquid is merely being carried round and round and is not flowing in any way. If a centrifugal pump is feeding a filter press the pressure cannot rise dangerously when the press gets full or dirty.

This very advantage possessed by centrifugal pumps can sometimes be a disadvantage. The fact that a centrifugal pump will run without mechanical damage against a shut discharge valve often leads to a pump running for long periods doing no useful work. When a pump is running like this on liquor considerable damage may be done to the liquor in the pump. This is due to the friction of the revolving liquor on the pump casing, which generates considerable heat and darkens the liquor. Liquor pumps have often been opened up because they were not pumping properly and the impellers have been found caked with black burnt sugar. Recently (1937) at Plaistow Wharf a centrifugal pump casing split open and the contents consisted of a glowing mass of charred sugar. The pump had been running full of syrup for some hours against a shut discharge valve. As one of the principal tasks of the sugar refiner is the removal of colour, the practice of running a centrifugal pump against a shut valve on sweet liquor must be avoided.

If a centrifugal pump is pumping water the discharge valve can be shut against the pump without any damage being done, so that our boiler feed pumps, fresh water pumps and many others often run against shut valves, which is very convenient, but a small leak off must be provided to prevent the heat developed in the pump from generating steam.

As a certain pressure only is obtainable from a certain size of impeller running at a certain speed, higher pressures are often obtained by stringing several impellers together. The discharge of one goes into the suction of the next. By this means any pressure within reason can be obtained without going to very high speeds or to very large diameter impellers. In fact pressures can be obtained that could not—due to the mechanical difficulties involved—be obtained from a single " stage " by having several " stages." The electrically driven boiler feed pumps at Plaistow Wharf which run at 3,000 r.p.m., which is the highest speed that a 50 cycle motor can run, give a pressure of 900-lb. sq. in. although the pump impellers are little over a foot in diameter. There are six " stages " in these pumps ; the delivery of each of the first five stages go into the suction of their neighbouring stage.

OUTPUT FROM CENTRIFUGAL PUMPS.

The output of a centrifugal pump depends on the resistance against which the pump is pumping. The less the resistance the greater the flow, and the more the resistance the less the flow. When a certain resistance is reached it will be more than the centrifugal force generated in the pump can overcome and the flow will stop. The pump then churns round idly as already explained. This property of a centrifugal pump of giving large outputs when the resistance is low and gradually less output as the resistance rises can sometimes be used with great advantage—for example when pumping through a filter press. When the press is clean the pump will send large amounts of liquor through, but as the press gets dirty the pressure on it will gradually rise and less liquor will flow, but the pressure can never rise to a dangerous height owing to the automatic limitation of the pressure that a centrifugal pump possesses.

POWER REQUIRED BY CENTRIFUGAL PUMPS.

The power taken to drive a particular centrifugal pump is dependent on the amount of liquid being pumped and not on the resistance to be overcome on its journey beyond the pump. This sounds all wrong so we must try to make it clear because the motor driving the pump can easily be overloaded if this is not understood. It would seem quite certain that more power would be needed to exert a high pressure than a low pressure. This of course is quite true, so let us try to clear up the apparent contradiction.

Just what has the impeller of the pump to do? It has to spin round the liquid that is in it. When the pump is pumping against a shut valve the impeller is full of liquid and is running round really just like a flywheel and needing no power except that needed to overcome friction caused by the liquid pressing against the case. Now when the pump outlet valve is shut the pressure at the pump outlet will be highest yet the power taken by the pump will be comparatively small because no work is being done except churning. If the valve is opened liquid will flow out of the pump outlet and fresh liquid will be drawn into the pump inlet and this fresh liquid sucked in will be whizzed round by the impeller vanes. Once the liquid has been started spinning it takes very little power to keep it going. It is the starting from rest to about 100 miles an hour that takes the power. That it is the starting of a thing from rest and not the keeping of it moving that takes the power can be seen by considering something else familiar. It is almost more than one man can do to start a railway wagon, but once it is moving it requires a comparatively slight push to keep it going. The more liquid a centrifugal pump is pumping the more weight of liquid has to be started moving very quickly and consequently more power is needed.

Most of our pumps have to pump fairly high or against some other considerable resistance, so that the power they can use is limited. Take for example river water pumps. They have to pump the water up say 100 feet and with their particular size and shape of impeller 300 horse power is all the power that they can ever need. But suppose they were suddenly allowed to pump only 50 feet high, then the resistance to pumping would be only half and about twice the water would flow, which means that twice the water would have to be started spinning which would call for twice the power in the driving motor.

Of course a pump motor driving a pump which is pumping a quantity of liquid against a certain pressure will take less power than a pump pumping a similar quantity against a higher pressure. But the pumps will be different sizes or will be running at different speeds or will have impellers of different design.

As the power taken is dependent on the output (in quantity) of the pump, the output can be measured by the amount of power being taken. A glance at the ammeter of a motor driving a centrifugal pump will show whether the pump is pumping as it should. If for instance the river water pumps appear to be pumping insufficient river water the ammeters on the motors will show whether the water is being pumped or not. If the amperes are lower than usual then the water is not being pumped, and this can be due either to blockage in the suction or discharge lines or to worn impellers. If the discharge line is the trouble then the pump outlet pressure will be normal or high and the vacuum on the pump suction will be low. If the suction line is blocked then the vacuum on the suction will be high and the pressure on the outlet will be low. If the impeller is worn or if the pump is drawing air the suction vacuum will be low and the outlet pressure will also be low. If the amperes on the pump motor are normal then the water must be being pumped somewhere.

CONSTRUCTION OF CENTRIFUGAL PUMPS.

A centrifugal pump consists of a casing in which the impeller runs. The inlet is formed in the casing and comes to the centre of the impeller. The impeller is a very snug fit in the casing in order that there should be as little churning and " slip " as possible. Slip occurs if the liquid under pressure in the outer part of the casing can flow back to the middle or suction part of the pump, which happens if the clearance between the impeller vane and the casing is too great. When this happens the impeller just pumps the liquid round and round itself.

The outer part of the casing is shaped like a snail—a gradually thickening spiral which leads gently into the discharge pipe. This

shape allows all the liquid in any part of the pump to leave the vane tips at the same speed and all the liquid will maintain that speed without check or increase until the outlet is reached.

In order to centre the impeller in the casing—and this is important because the clearance is so small—an adjustable thrust bearing, consisting of a double row of ball bearings, is provided on the spindle. As the spindle has to pass through the casing, a joint in the casing, to prevent the liquid coming out round the spindle, must be provided. This joint is called a " gland." As glands are important and are necessary on many different pieces of plant they will be discussed in a separate section.

GLANDS.

When a moving shaft or spindle in any machine passes through a casing into another part of the machine where the conditions are different on either side of the casing, a gland is provided. The different conditions on either side of the casing may be either high pressure on one side and low pressure on the other, or liquid on one side and air on the other, or different gases on either side. For example, every valve has a hand wheel in the air fastened to a spindle which passes through the valve casing into the body of the valve. The valve spindle must move freely but there must be no leaks between the air outside the valve and whatever may be inside the valve. Similarly a centrifugal pump spindle must pass through the pump casing in order that the motor may drive one end of the spindle while the other end is attached to the impeller inside the pump casing Again the piston rod of a reciprocating pump or steam engine has to slide in and out of the cylinder freely but without allowing leaks.

The device which allows the rod or spindle to move freely and which is alleged to prevent leakage is called a gland, and it is a sorry disgrace to the world's engineers that they have been designing and making glands for over 100 years and have not yet learnt how to make one that will keep reasonably tight for any length of time without glass-case conditions or constant attention.

A gland is constructed as follows :—Where the gland is to be, namely where the spindle is to pass through the casing of the valve, pump or whatever the plant is, the metal of the casing is thickened into a " boss " of about four times the thickness of the diameter of the shaft or spindle that is to pass through. A hole is bored through the thickened boss which will pass the shaft or spindle quite freely. The greater length of this hole is now enlarged until it is nearly twice the diameter of the spindle. A sleeve or tube is made to be a loose fit on the spindle and a fair fit in the enlarged hole. This sleeve is slipped on to the spindle and inserted into the hole. Soft

material called packing—usually greasy cotton or greasy asbestos impregnated with graphite—is wrapped round the spindle and pushed into the hole by means of the sleeve which can be forced into the hole, thereby squeezing the packing on to the spindle and the shoulder in the hole and making a joint on both. The gland sleeve is usually tightened into the hole by means of nuts on several studs pulling on a flange on the sleeve, though sometimes the sleeve itself is made to screw into the hole.

A gland is very easily damaged by rough treatment—that is one of the reasons why glands are so unsatisfactory. The chief ways in which the gland is illtreated are screwing in the sleeve far too tight when the soft packing gets burnt by friction on the shaft and becomes hard, scores the shaft and naturally can then be hardly expected to make a tight joint; or by tightening the nuts up unevenly thus forcing in the sleeve askew.

When a gland is to be packed, the packing should if possible be in the form of moulded rings. If packing must be used which has to be cut off a coil then exactly the right length should be cut off, the ends should be cut very clean and at the correct angle and as much packing as possible should be inserted. The sleeve should then be screwed up finger tight only and the gland should be put on load. It should then be tightened up just sufficiently to stop leaking and no more, and the greatest care should be taken to tighten up all the nuts evenly.

CHURNING IN OF AIR.

The output of a centrifugal pump which is pumping sugar liquor should always be regulated by means of the discharge valve and not by means of the suction valve. If the suction valve is used there may be a considerable vacuum at the centre of the impeller and air may be drawn in through the glands. This churning in of air into a sugar liquor in a centrifugal pump is very bad and must always be avoided. Apart from the glands air can also be drawn into the pump suction unless great care is used to see that the tank or gutter from which the liquor is being pumped is kept full. Liquor or syrup has sometimes been doubled in colour after being pumped, simply because the pump has been allowed to draw air at the suction. Here are some figures taken in January, 1931.

Syrup running off chars ... ... 23 colour

Syrup running into tank after pumping ... 52 colour
       (gutter empty and air being drawn in)

Syrup running into tank after pumping ... 25 colour
       (gutter kept full by means of pump discharge valve)

PISTON AND PLUNGER PUMPS FOR LIQUIDS.

Unlike centrifugal pumps, piston and plunger pumps are constant output machines. Each stroke of the pump delivers the same quantity and if the resistance to pumping increases the pressure goes up until something gives. Plunger pumps are generally used for high pressures and piston pumps for lower pressures. A piston pump can give double the output of a plunger pump of similar size because a piston pump can be made double acting, as will be explained later. Piston or plunger pumps—reciprocating pumps as they are called (Latin—moving back and forth)—are large, occupying from four to eight times the space of the corresponding centrifugal pump. Reciprocating pumps have a lot of mechanism which requires a lot of lubrication and maintenance. They have at least two, often eight, valves which can stick, leak and wear. They have reciprocating glands which give a lot of trouble on sugar liquors because the liquor partly dries out on the pistod rod and forms grain which cuts and grinds the packing of the gland. But for very heavy syrups it is often necessary or desirable to use reciprocating pumps. Reciprocating pumps take less power than centrifugal pumps. For very high pressures such as are used on hydraulic machinery plunger pumps are almost always used.

PLUNGER PUMPS.

A plunger pump consists of a pump chamber, which can be of any shape, provided with a gland through which the plunger works in and out by means of a crank or other suitable drive. The pump chamber is provided with an "inlet" or "suction" valve and a "discharge" or "exhaust" valve. These valves sometimes take the form of balls but more usually are like the lid of a kettle.

When the plunger is pushed into the pump chamber—assuming the chamber to be full of liquid—an amount of liquid equal to the volume of the plunger must be forced out. Let us imagine that the discharge valve is like the lid of a kettle and that the inside of the kettle is the inside of the pump chamber. Any pressure inside the kettle—produced by, for example, pushing something down the spout—will lift the lid and the excess contents will be driven out of the lid opening. That is what happens during the inward or pumping stroke of the plunger. Now as the return stroke commences there is no pressure inside the pump chamber or kettle so that the valve or lid drops back on account of its own weight. As the plunger moves further out a suction or vacuum will occur inside the chamber and draw the discharge valve tight down on to its seat. Now assume that the kettle has a hole in its bottom closed by a lid inside the kettle just like the hole and lid in the top. Such is the arrangement of the pump inlet valve. When the withdrawal of

the plunger causes a vacuum inside the pump chamber the top lid or valve will be pulled down tight and the bottom lid or valve will be pulled up or opened and this will allow liquid to flow into the chamber from the supply.   When the plunger stops moving on its outward stroke the valve or lid which has been allowing liquid to flow into the pump will fall on to its seat due to its own weight and as soon as the plunger starts to slide in and cause a pressure this bottom lid or inlet valve will be pressed tight down on to its seat, and as already explained, the discharge valve is opened.

A plunger pump only pumps on the inward stroke ; on the outward stroke suction and filling of the pump chamber are happening. A pump such as this is said to be single acting when only one stroke does useful pumping work.   In order to get a steady flow from a plunger pump it is necessary to have more than one plunger.   Three are generally used.   Plungers are usually driven from a crankshaft through connecting rods.   Plunger pumps generally work quite slowly.   The plungers work through glands.   If the pump is large then the glands have also to be large which is a drawback.   A plunger pump is cheap and easy to make.   The plunger is just a round metal rod and the only part it has to fit is the gland which is adjustable.

PISTON PUMPS.

A piston pump works on exactly the same principle as a plunger pump and the valve arrangements are exactly the same in each. Instead of a plunger working in and out of a chamber of any shape through a gland the same size as the plunger, a piston works to and fro in an accurately bored cylinder and a comparatively small piston rod works the piston through a gland.   A piston is a plug which is an easy fit in the cylinder and the liquid-tight joint is made by means of piston rings.

A piston ring is a ring of hard springy metal, usually cast iron or bronze, which is made a little bigger than the cylinder it is to work in.   It is then cut through in one place so that it can be squeezed into a smaller diameter.   Grooves are cut in the piston to accommodate the rings which spring tight against the cylinder walls and make the piston in effect into an expandable plug.

It is a curious and surprising thing that a piston with its rings sliding in a cylinder gives as a rule less trouble than the piston rod of perhaps a sixth of the diameter of the piston and the gland it slides in.

Sometimes piston pumps are made single acting with the front end of the cylinder open, but generally advantage is taken of the fact that a piston pump can be made double acting by operating the

piston through a piston rod working through a gland in the front cylinder cover and fitting another set of valves in the front part of the cylinder. The piston can then be pumping with the front side of the piston when it is sucking with the other side. This allows the output of the pump to be doubled without materially increasing its size. It also greatly smooths out the pulsations in the outflow.

OUTPUT OF PISTON AND PLUNGER PUMPS.

The output of a piston or plunger pump is obviously just the amount of liquid that can be displaced by the piston or plunger at each working stroke. So that, assuming that the chamber or cylinder is completely filled at each suction stroke, the quantity pumped will be exactly proportional to the speed of the pump. The resistance against the pump can have no effect whatever on the output—the piston or plunger cannot displace more or less than their own volume on each working stroke. The only way to alter the output is to alter the speed. Of course a worn, old leaky pump will pump less against a high resistance than against a low resistance, but no one in their senses would deliberately instal a worn-out pump in order to get a lower output.

PRESSURE FROM PISTON AND PLUNGER PUMPS.

The pressure that a reciprocating pump can give depends only on the resistance against which the pump is pumping, the mechanical strength of the pump and the power of the motor driving it. The piston or plunger is being driven into the pump chamber or cylinder; it follows that the liquid in equal volume must be forced out. If a valve is shut against the discharge of a reciprocating pump one of the following things must happen :—the drive must fail, that is, the belt must break or come off, the coupling shear, or the fuses or cutout must stop the motor or the motor must burn out ; the discharge pipe must burst or a joint blow out ; the pump cylinder, cylinder-head or pump chamber must burst ; or the pump driving gear, crank-shaft, connecting rod, etc. must break. The output of the pump cannot be controlled like that of a centrifugal pump by throttling the outlet valve, but preferably by slowing it down and speeding it up or stopping it periodically. If this is impracticable then it must be controlled on the suction side by means of a valve.

POWER TAKEN BY PISTON AND PLUNGER PUMPS.

As the output of a reciprocating pump depends only on the speed and as normally these pumps are run at constant speed the power taken can only vary with the resistance to pumping. This means that the power will vary directly with the pressure at the pump outlet.

COMPARISON OF CENTRIFUGAL WITH RECIPROCATING PUMPS.

It is interesting to note that output, power and pressure given or taken by the two different kinds of pump—centrifugal and reciprocating—depend on totally different things.   Here is a little table showing these differences which have been explained in the foregoing sections :—

		Centrifugal Pump.	*Reciprocating Pump.*
OUTPUT	depends on	Resistance to Pumping.	Speed of Pump.
PRESSURE	depends on	Speed of Pump & dia. of Vane.	Resistance to Pumping.
POWER	depends on	Quantity pumped.	Pressure at Outlet.

It would probably be thought that we would select the type of pump to be used for different purposes having regard to the different qualities that we have been considering, but actually we do nothing of the sort.   The centrifugal pump is so much simpler, so much cheaper, and so much smaller that we only use a reciprocating pump if a centrifugal pump will not do the job.   The reciprocating pumps in the refinery are quite a small number and are confined to the pumping of very heavy syrups and massecuites or to evaporator extraction pumps where the greater suction that a reciprocating pump will give is an advantage.

SCREW PUMPS.

All kinds of curious pumps have been tried on heavy syrups and massecuites in place of piston pumps.   For many years we used a screw pump where the massecuite ran on to a large screw.   Meshing with the screw was an endless chain made with plate links to fit the screw threads.   The chain scraped the material off the screw thus making the screw " screw " or force the stuff into the pump outlet. Many men will still remember these old pumps at Plaistow Wharf— one working and two being repaired.   We have also used a number of pumps where the pumping elements were two opposite-handed screws meshing with each other ; but their action was really that of a gear pump.   They got very hot, used a lot of power and gave a deal of trouble.

GEAR PUMPS.

The Albany or gear pump is an excellent pump for moderate pressures and certain liquids.   It is simpler and more reliable than a reciprocating pump and it gives a much higher pressure at much

lower speeds than a centrifugal pump. It gives a perfectly even outflow and it does not have to run fast, but it requires complete and continuous lubrication, so that it is particularly suitable for pumping oil. Most machines that have pressure lubrication have their oil pumped by a gear pump. The oil pump on almost every lorry or car is an Albany gear pump. The oil pumps on our Edwards Vacuum pumps are gear pumps.

The gear pump works as follows:—Two gear wheels of equal size are meshed together and fitted into an oval case. One of the wheels is driven and this wheel drives the other. The wheels are a running fit in the case on their sides and along all of their tooth tips except that part near the meshing point. The oval case therefore has straight sides and semi-circular ends. If the tooth spaces are filled with liquid the liquid will be carried round the outside of the casing in the tooth spaces and will be squeezed out where the teeth enter the opposite tooth spaces at the meshing point. This side of the meshing point will consequently be under pressure and will, if provided with an outlet, form the delivery of the pump. As the teeth leave the meshing point on the other side of this point there will be an emptiness or vacuum so that an opening provided here will form the suction of the pump.

THE MONTE-JUS.

The Monte-jus (French for juice lift) has (1938) disappeared from T. & L. refineries. The writer believes that this disappearance may be only temporary as the monte-jus has certain great advantages and was condemned and thrown out chiefly because it was so badly made and badly applied.

The monte-jus will handle anything that will flow through a pipe. The material pumped passes through no mechanism and therefore suffers none of the damage that we know takes place in some of our pumps. For instance, the calcium carbonate precipitate in carbonatation liquors is damaged by the punishment it receives in the impellers of the centrifugal pumps which pump the saturated brown liquor to the presses. Grain in a massecuite is broken up by the piston and valves of a piston pump. No such damage occurs in a monte-jus.

A monte-jus is simply a closed tank with an outlet pipe at the bottom and an inlet pipe at the top. At the top also is a pressure pipe and the vessel is fitted with a safety valve, a liquid level guage and a pressure gauge and a blow off valve. Liquid to be pumped is run into the monte-jus. When it is full the inlet valve is closed and the outlet valve is opened. Pressure, either steam or compressed air dependent on whether the diluting and heating effect of steam is

permissible, is then applied through the pressure pipe and the contents are blown out of the outlet. When empty all three pipe valves are shut and the pressure remaining inside the vessel is blown off through the blow off valve. The monte-jus is then ready for refilling.

The monte-jus that we had were hand operated, another reason for their disappearance, though by grouping a number together as was very neatly done in Liverpool. this objection was minimised. Where compressed air is used to operate monte-jus an air pump is of course required. But the combination of air-pump and monte-jus may be more desirable than for example a massecuite pump. There is no doubt that an automatic monte-jus could be designed and made and possibly such a plant will be the pump of the future for very heavy syrups.

FANS.

Fans are of two types, propeller and centrifugal. The propeller fan is used usually in the smaller sizes for moving small volumes of air at low pressures and is simply a small windmill. Very powerful fans are now being made with propellers similar to aeroplane propellers, and these are very efficient, so that it is quite likely that the fans of the future will be of the air screw type. A windmill or propeller is just a part of a screw.

The centrifugal fan works on just the same principle as the centrifugal pump for liquids and it follows the same rules regarding output, pressure and power. The mechanical construction is however quite different. Whereas the vanes on a liquid centrifugal pump are long, those on an air centrifugal fan are quite short. The best shape and angle or curve has not yet been agreed by engineers. There are many different shapes but there seems to be little to choose between them.

BLOWERS.

Fans only deliver air at low pressures. Quite a powerful fan will only give a pressure of a few inches of water. When air is required at rather higher pressures, up to a few pounds per square inch, rather different machines are used—these are called blowers. For high pressures, reciprocating pumps are generally employed. A blower can be made up of a fan of several stages, just like the many-staged centrifugal pump for high pressure on liquids. The other type in common use is the Rootes blower which is simply a gear pump with only two huge teeth on each wheel instead of a lot of small ones.

VACUUM PUMPS.

The " vacuum " or space with nothing in it was first produced by an Italian, Torricelli, when he made the first mercury barometer in 1643.   If a glass tube more than 30 inches long and closed at one end is filled with mercury and then corked up it can be turned upside down and the corked end immersed in a dish of mercury.   If the cork is now taken out of the open end the mercury will stand up in the tube about 30″ above the level of the mercury in the dish. However long the tube, the mercury will only stand up about 30″. Above the mercury in the tube is " nothing," or a perfect vacuum or emptiness with only a trace of mercury vapour.   Some people find it difficult to understand that the difference of pressure of a vacuum and of the surrounding atmosphere is due only to the pressure of the atmosphere.   They cannot believe that the air can exert such a great pressure, but a little thought about the barometer must convince them that it really is so.

Consider the barometer again.   A tall glass tube with its closed end uppermost is standing up in a dish.   Tube and dish are full of mercury and yet the mercury does not run out of the tube more than the amount needed to leave a column about 30″ high.   Everyone will answer that the vacuum is holding it up, which may be true enough but what is vacuum ?   What is the difference between the mercury in the dish and the mercury in the tube that makes the one lot stand up above the rest ?   Only that nothing is pressing on the top of the mercury in the tube while the air is pressing on the mercury in the dish.   If our glass tube was $1\frac{1}{8}$″ in diameter, its area would be just about one square inch, and if we took the amount of mercury that the atmosphere could hold up in this tube we should find that it weighed just about 15 pounds.   So that the air is exerting a pressure at sea level of about 15 lb. per square inch on everything.

A German, von Guericke, was very interested in this vacuum when he heard about it, and tried many ways of producing it with a pump.   He was eventually completely successful and invented and made the pump that we now call the " dry reciprocating vacuum pump."   In 1654, nearly 200 years before the first railway train ran, he gave a demonstration before Emperor Ferdinand III.   He had made two copper hemispheres about two feet in diameter.   He placed them together with a joint of oiled leather between the edges. He then applied his vacuum pump, which could be operated by a small boy—there was no steam engine or motor to drive it.   In this way, so good a vacuum was produced that sixteen horses in two teams of eight could not pull the two hemispheres apart.   Von Guericke correctly attributed the force holding his hemispheres together to the pressure of the atmosphere.

There are many types of vacuum pump, some of which will now

be described. The large, slow speed, dry reciprocating pumps, direct descendants of von Guericke's, are very effective for moderate vacuum but they are machines that need to be well housed, kept clean, well lubricated and well-tended generally. They are expensive, occupy a lot of space and use a good deal of power, expecially if asked to give high vacuum. The Edwards water-sealed reciprocating pump is generally of three cylinders, and runs at a fairly high speed. It will usually give a better vacuum than the dry pump, and uses much less power at high vacuum. But it needs a lot of cold, clean, sealing water and uses a lot of power when lifting its vacuum. Theoretically, the ejectors, either water or steam, should be the best. Our experience has been that they are extravagant and inefficient; possibly our conditions may not have been favourable. Rotary vacuum pumps have proved unsatisfactory for our work and will therefore not be described.

DRY RECIPROCATING VACUUM PUMPS.

A dry reciprocating vacuum pump is a double acting piston pump just the same as a piston pump for liquids. In order to make it more suitable for its job there are a few small differences. For example, the valves are mechanically operated from the crank shaft instead of being operated by the pressure in the cylinder. If the discharge valve is operated by pressure in the cylinder it means that there must always be quite an excess of pressure inside the cylinder to keep the valve open during the discharge or exhaust stroke. By operating the exhaust valve mechanically the pressure inside the cylinder is hardly above that of the atmosphere outside. The importance of this will be seen in a minute. Again, if the vacuum in the cylinder were relied on to open the suction valve then the valve would not open until there was quite an appreciably higher vacuum inside the cylinder than in the pipe leading to the condenser or whatever is attached to the pump. To see the importance of keeping the pressures as near as possible the same on either side of the working valve, let us follow the pump through one cycle, that is one complete revolution of the crankshaft.

For simplicity we will consider one side only of the piston. Assume that the piston has almost reached the end of the cylinder on the discharge stroke. The inlet valve has, of course, been shut throughout the stroke. The exhaust valve has been open for a short time and is now closing. The pressure in the small space between the piston and the cylinder head and in the passages leading to, or the pockets containing, the valves will be at atmospheric pressure because the exhaust valve has been open to the atmosphere. Just at the instant when the piston reaches the end of the stroke, the exhaust valve shuts. The piston now begins to move away from the cylinder head and thereby increases the volume of the small amount

of air left in the cylinder at the end of the exhaust stroke. Suppose that the vacuum in the condenser to which the pump is attached is 25″, then the pump cannot do any useful work until it has expanded the air left behind in the cylinder to a higher vacuum than 25″. When the piston gets well down the cylinder the inlet valve is opened and it shuts the moment the cylinder volume is greatest, that is at the exact end of the stroke. The piston starts back and compresses the air or gas and towards the end of the stroke, when the pressure is at or near atmospheric, the discharge valve is opened and the gas or air is exhausted to the atmosphere. The cycle then recommences. Now it will be clear that at some vacuum, dependent on the clearance between the cylinder head and the piston and the size of the valve passages or pockets, the piston will reach the end of its suction stroke, and all that it will have done will have been to expand the air or gas left behind in the cylinder at the end of the previous stroke. There will be no sucking power to increase the vacuum in the condenser. The pump will have reached its limit. When the piston drives back again it will not push any air out of the exhaust valve because all it will have done will have been to re-compress the air in the cylinder back to atmospheric pressure.

The essential requirements for the design of the pump are now clear. The piston must be made to go as near as possible to the end of the cylinder without touching the cylinder cover. The valves must be brought as near to the working part of the cylinder as possible and not be buried in deep pockets or put at the end of long passages. If these points are attended to, a dry vacuum pump will give quite a good vacuum and is an excellent and reliable machine provided it is well looked after.

Many dry air or vacuum pumps have a valve arrangement which is designed to remove most of the air left in the clearance space at the end of the discharge stroke. Consider a double-acting pump. When the piston is exactly at the end of the suction stroke on one side of the piston it is exactly at the end of the discharge stroke at the other side. The pressure in the cylinder on the discharge side is atmospheric, while the pressure on the other side is that of the vacuum in the pipe leading from the pump. At this moment, all the valves are shut. A small special valve, called a " trick " valve, is now opened which puts one side of the cylinder into communication with the other. At once the pressure equalises. This can do no harm to the side that has just finished its suction stroke because the inlet valve is shut. It can do tremendous good to the other side which has finished its exhaust stroke because instead of the clearance spaces being filled with air at atmospheric pressure, the space will be at quite a good vacuum and the piston will reach a vacuum above that in the line much sooner along its stroke. This arrangement should have improved the performance of the dry pump out of all recognition, but

it is a peculiar thing that many dry pumps not provided with this trick valve appear to be just as efficient as those that have it.

In a dry reciprocating vacuum pump the piston is driven to and fro in the cylinder by means of a connecting rod which is driven by a crank on the crankshaft. The valves are operated in a number of different ways, just as are those of steam engines, and the various methods need not be gone into in detail.

THE EDWARDS PUMP.

Now if by some means or other the clearance space at the end of the discharge or exhaust stroke could be reduced to nothing, or practically nothing, a big step forward would have been taken. To produce the same vacuum the pump could be much smaller than the corresponding dry pump, because a large part of the dry pump's stroke is wasted in just expanding the air left in the clearance space. The design of the pump has not got to be very bad, nor the vacuum very high, for this waste to amount to half the capacity of the pump. The object of making the exhaust valve mechanically operated is to ensure that the clearance air is at the lowest possible pressure. If the clearance space could be eliminated, then automatic valves could be used.

The Edwards pump has no clearance space filled with air. At the end of the stroke the clearance space and the valve pockets are filled with water. The cylinder is always arranged vertically with the end of the cylinder containing the discharge valves at the top. These discharge valves consist of thin metal plates which lift much more easily than heavy kettle lid valves. These thin plate valves may not always seat quite so quickly as an ordinary pump valve, but in the Edwards pump this does not matter as the valves are always under water, and any little leak will be water which will not expand and not air which can expand. There are no movable inlet valves on the Edwards pump. The piston, as it nears the bottom of the stroke, uncovers ports in the cylinder wall which are the inlet openings.

The Edwards pump is single acting. The down stroke is the suction stroke and the up stroke is the discharge stroke. The cylinder barrel in which the piston works is open-ended and stops short of the bottom of the cylinder whose bottom end cover is cone-shaped with the point of the cone downward. The bottom of the piston is also cone-shaped to fit the shape of the bottom of the cylinder. Water is introduced into the suction of the pump and runs into the bottom of the cylinder underneath the mouth of the barrel where it lies in a pool in the bottom of the cone. When the piston reaches the bottom of its stroke it violently displaces the water and drives it, by means of suitably shaped passages, on to the top of the piston. At this point the top and bottom of the cylinder are in direct com-

munication through the open end of the barrel and the inlet ports. As the piston has been descending without any valve being opened, there will be a high vacuum on the top of the piston so that the air is sucked into the cylinder with the " injection " water. The piston at once starts to rise and before the water can run off its top the piston has passed the ports, and the water and air are driven up to the top of the cylinder. On the way up the cylinder, the water seals the joint between piston and cylinder, and lubricates the piston and cylinder. When the piston reaches the top, the air and water are pushed out through the thin plate exhaust valves and the clearance between the piston and the cylinder head is left full of water.

The exhaust valves are placed all round the top of the cylinder in a large chamber formed above the cylinder head. By means of a dam and overflow, this chamber is kept full of water and the valves are always completely submerged. The water runs away from about halfway up the valve chamber and the air escapes through the exhaust pipe in the top.

When the rising piston gets near the top of its stroke, the pressure inside the cylinder is enough to lift the valves against the few inches of water above them. The air escapes, and after all the air has been driven out the excess sealing water is forced out and the clearance space and valve pockets are left full of water.

That is what is supposed to happen. Like many other things, it does not quite pan out. The water above the piston on the up stroke is slopping violently about and as the pump must run fast in order to trap water above the piston at all, there is no time for the rough water to quieten down. The result is that the air and water are very much mixed together and the water that fills the clearance space at the end of the stroke is full of air bubbles. These expand on the down, or suction, stroke and prevent the pump reaching its theoretical efficiency. The theoretical maximum vacuum of the Edwards pump is that at which the sealing water will boil. If the sealing water has a temperature of 60°C, the pump cannot give a higher vacuum than 24″. If the water is at 40°C a vacuum of 27¾″ should be obtainable. In practice the vacuum is limited by air dissolved in the sealing water, which comes out at high vacuum. The cooler the water—that is the higher the vacuum aimed at—the more air dissolves in the water on the compression stroke.

The Edwards pump is an example of true genius in invention. Anyone can design a complicated machine, but to design a machine which is a great improvement on anything yet produced, and one that is at the same time mechanically simpler, is something that should have our respectful admiration. The Edwards pump was designed for the surface condensers of ships—to remove the air from

the condenser and the condensed water simultaneously. The condensed water in that case was the pump sealing water. Our Edwards pumps run with great reliability and require very little attention. The highest vacuum piece of plant in any of the T. & L. refineries is the Goldie Kestner. which operates at little more than an inch of absolute pressure. This evaporator has had the same Edwards pump on it for over 30 years,

THE EDWARDS PUMP.

VALVES
SEALED
BY WATER

VACUUM
FORMED
BEHIND PISTON

WATER SEALS
AND LUBRICATES
PISTON
AND PISTON-ROD

GLAND

EXHAUST

SEALING WATER
INLET
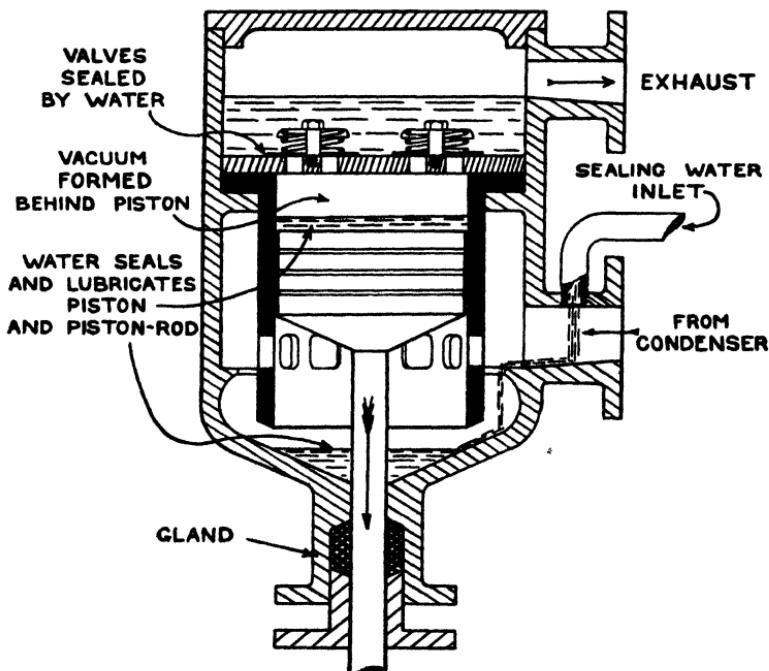
FROM
CONDENSER

Fig. 68
Edwards Pump—Start of Suction Stroke.

Fig. 68 shows a section of the pump cylinder. The piston works up and down inside the pump barrel which is drawn in black. The barrel is open at the bottom and is provided with ports a little way up from the bottom. The top of the cylinder barrel is closed by a plate

*carrying the valves. The valves are light discs and are held shut by
light springs. The inlet from the condenser goes into the space
surrounding the barrel. The bottom of this space is cone-shaped and
a supply of cool water is fed in continuously into this space. The
water runs into the bottom of the casting where it seals and lubricates
the piston rod. The outlet of the pump is a few inches above the valve
plate so that the valves are always under water. In Fig. 68, the piston
is shown soon after the beginning of its down, or suction, stroke. A
complete vacuum is formed behind the piston. The valves are kept
shut by their springs and by the vacuum beneath them. They are also
sealed by water so that if they do leak they will leak water and not air.
The piston is sealed and lubricated by water.*

PORTS UNCOVERED –
AIR RUSHES INTO
VACUUM
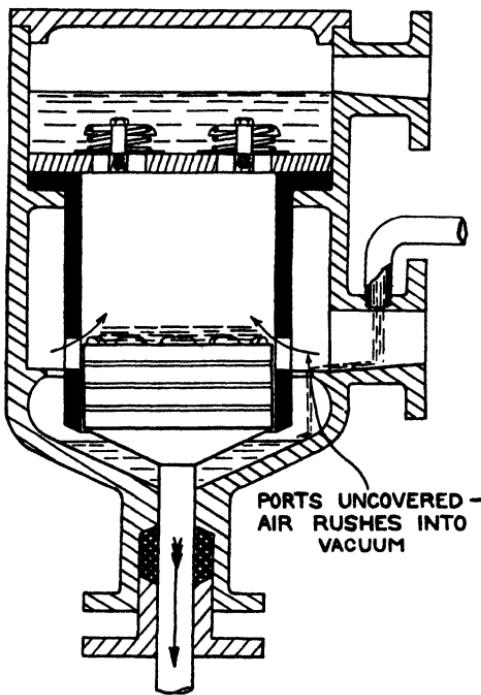
Fig. 69
Edwards Pump—Suction Point.

*Fig. 69 shows the piston nearing the bottom of the stroke. The top
edge of the piston has uncovered the ports in the wall of the barrel and
the air is rushing into the vacuum behind the piston.*

Fig. 70 shows the piston at the bottom of its stroke. The cone-shaped base of the piston drives into the conical base of the cylinder casting

DESCENDING PISTON
FORCES WATER ROUND
CURVED CASING THROUGH
PORTS INTO CYLINDER
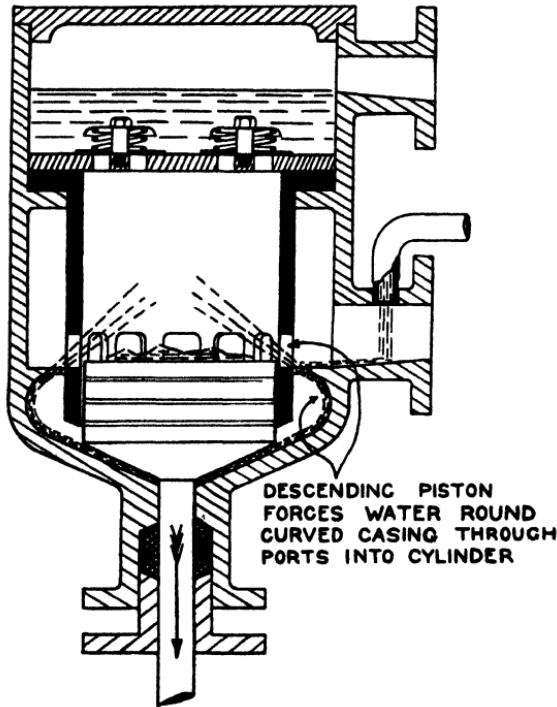
Fig. 70
Edwards Pump—Injection Point.

and forces the water round the curved casing so that it shoots through the ports in the cylinder barrel on to the top of the piston.

Fig. 71 shows the piston well started on its upward journey. The injected water and the sucked-in air are being carried up the cylinder.

AIR & WATER
CARRIED UP BY
PISTON
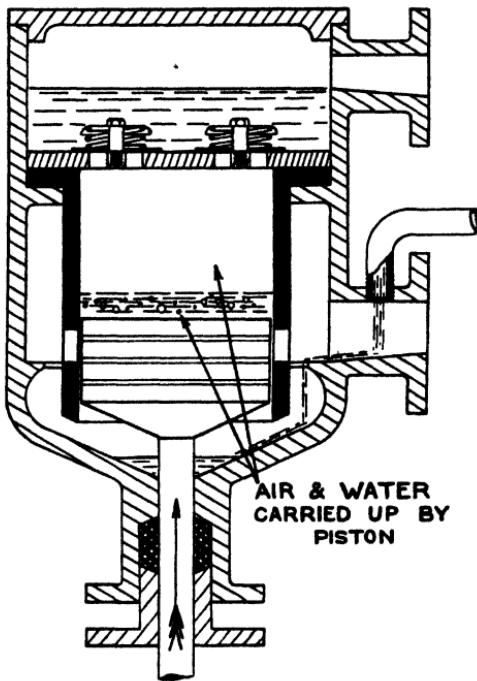
Fig. 71
Edwards Pump—Compression.

Fig. 72 shows the piston at the end of its upward stroke. The air is forced out through the valves together with the excess water. The

clearance space between the piston head and the valve plate is filled with water so that when the piston begins its downward stroke it forms a vacuum at once without having to expand the air that would have

AIR & EXCESS WATER
DRIVEN OUT-
VALVES LIFTED
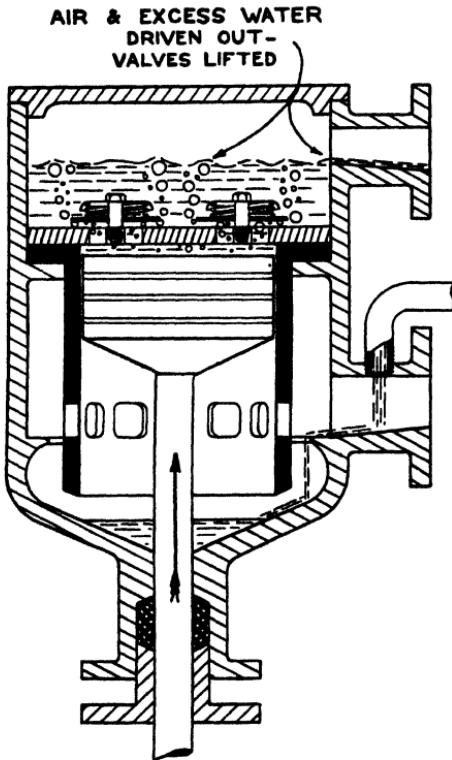
Fig. 72
Edwards Pump—Exhaust.

occupied the clearance space had there been no sealing water. The air and water pass into a separator from the exhaust pipe where the air escapes and the water is sent to the process or is passed through coolers and returned to the inlet of the pump again.

POWER REQUIRED BY RECIPROCATING VACUUM PUMPS.

The power required by a reciprocating pump is found by measuring the difference in pressure on either side of the piston at all points in the stroke.

In the Edwards pump, at very high vacuum, the upper side of the piston on the down stroke is an almost perfect vacuum, while the under side of the piston has the high vacuum of the condenser. There is very little pressure difference. On the up stroke the pressures are the same on each side at the beginning of the stroke and, while that on the bottom side remains at the high condenser vacuum, the pressure on the top of the piston gradually rises until the exhaust valves are opened by the pressure rising above atmospheric pressure. At low vacuum there is a great pressure difference on the down stroke because the top of the piston is still an almost perfect vacuum whereas the under side has the low vacuum of the condenser. On the up stroke there is more air to discharge so that it follows that the exhaust pressure will be reached sooner and will last longer although the pressure on the under side will be more than in the high vacuum condition. The Edwards pump will, therefore, use less power at high vacuum than at low vacuum.

The large power consumption of the Edwards at low vacuum can be greatly reduced by fitting a pipe between the upper and lower parts of the cylinder and fitting an automatic suction valve in this pipe. Then, on the down stroke at low vacuum, the space above the piston will fill with air through this pipe and valve, which will reduce the pressure difference throughout the suction stroke. The valve will remain shut during the discharge stroke so that the efficiency of the pump will not be affected. At high vacuum there will not be a sufficient pressure difference to bring the valve into action.

A double-acting dry pump uses more power at high vacuum than at low vacuum. At low vacuum the suction stroke has an average low vacuum while the discharge stroke never exceeds atmospheric. The lower the vacuum, the more nearly will the pressure on each side of the piston on the two strokes be. At high vacuum, on the other hand, the side that is exhausting will be near or at atmospheric pressure whereas the suction side will be at the high vacuum.

THE STEAM EJECTOR.

When crossing the road, one sometimes passes very close to a very fast moving vehicle. When standing on a railway platform, a fast train sometimes passes very close. In both these cases one is very conscious that the air alongside the fast-moving thing is being

dragged along with it, and one often feels in danger of being sucked along too.   This dragging along of the surrounding substance by a fast-moving thing is the principle on which the ejector works.

An Ejector is a small box or chamber to which is connected the vacuum pipe leading to the condenser or whatever else the vacuum is wanted for.   Sticking well into one end of the box is a nozzle through which high pressure steam can be blown.   Sticking into the opposite end of the box, and quite close to the nozzle, is the "throat" or outlet pipe.   When high pressure steam shoots across the box from the nozzle into the throat at a tremendous speed, it causes a very powerful drag on the air in the box and will pull the air along with it, causing a vacuum to be created in the box.   The throat is made in two tapers which have been found to be the most effective shape.   Once in the throat, the steam and air are mixed and cannot separate.   The throat at first tapers down to a smaller diameter. This makes the steam go faster, thus ensuring that it gets well into the throat with the air it is dragging along.   The throat then tapers gradually larger so that the steam slows down more and more until, at the discharge, it is going quite slowly.

The steam ejector is very efficient, especially at high vacuum. Above about 26″, a steam driven vacuum pump will use more steam to maintain a vacuum than will an ejector.   Our trouble is to find a use for the exhaust steam.   The exhaust from a steam pump could be piped at any convenient pressure to process, but the ejector does not work efficiently against a back pressure, and the steam contains air.   A steam and air mixture is very corrosive, and air in the heating element of a pan or evaporator may be troublesome to remove.   We are only using ejectors as vacuum pumps on our boiler feed water de-aerators (1938).   All modern power stations use nothing else, but they need to work if possible at 29″ vacuum—almost impossible to get with even an outsize in pumps.   They can use the exhaust steam to heat their feed water—we already have an unlimited supply of such low-grade heat in our pan vapour.   The air to be removed from their surface condensers is negligible compared to that which we must remove from our jet condensers.   The ejector has no moving parts, nothing to wear out and nothing that needs lubrication.

THE WATER EJECTOR.

The water ejector works on exactly the same principle as the steam ejector except that water is blown through the nozzle instead of steam.   We have found that the horse power needed to drive the motor which is needed for pumping the water is much more than the motor driving an Edwards pump of equivalent capacity.

GAS PUMPS.

The only other important class of pumps in the refinery are the pumps that pump the CO_2 for the carbonatation process. The gas is boiler flue gas cooled and washed. We use two kinds of pump. First and best, but very expensive and occupying much space, are slow-speed dry reciprocating pumps identical with dry vacuum pumps. The other type is the Elmo pump which is a small high-speed centrifugal pump sealed with water. It is a mixture of fan and liquid centrifugal pump. It uses a great lot of water and gives only a low pressure, and with our gas corrodes very quickly. Its small size enables it to be used where there is no room for a large reciprocator.

CHAPTER 10. VACUUM PANS.

And say which grain will grow, and which will not.

SHAKESPEARE—Macbeth—1605

Before reading this chapter, the reader is asked to be sure that
he understands the sections in Chapter 2 on " Solubility," " Satura-
tion and Supersaturation " and the sections in Chapter 5 on " Specific
Heat," " Total Heat," " Latent Heat," " Sensible Heat," " Saturated
and Superheated Steam," " Flash," " Evaporation," and " Con-
denser Loss."

REASONS FOR VACUUM BOILING.

The object of boiling a sugar solution is to drive off part of the
water.   In an Evaporator, the object is to concentrate or " thicken
up " the liquor or syrup—to increase its Brix.   In a Vacuum pan
this thickening up is carried further so that solid sugar is thrown out
of the solution as crystals.

The sugars are substances which, when in solution, are fairly
easily changed or broken down into other substances.   Quite a low
temperature will turn the sugars brown by forming traces of other
substances, called caramels.   Heat also helps inversion and invert
sugar turns brown more easily than sucrose.   It is therefore·of the
greatest importance to boil sugar liquors at the lowest possible
temperature.   On page 90 it has been explained that as the vacuum

goes up, so the boiling point of water goes down. This also applies to sugar solutions. Therefore we boil our sugar under as high a vacuum as other conditions will allow. These other conditions will become clear as we go along.

Another reason for boiling at as low a temperature as possible is that it enables a lower pressure of steam to be used for heating the pans. It is important that the boiling of sugar should be as quick as possible because the longer the time the sugar is boiling, the more brown colour will be made. Now suppose that we have found by experience that we need a temperature difference of about 80°C. between the steam and the boiling sugar liquor in order to boil the sugar properly and quickly. If we boiled at atmospheric pressure we see from the steam table on page 92 that we should need a steam pressure of 130 lb. per sq. in. to give us this temperature difference. But if we boil at a vacuum of about 24″, we shall only need a steam pressure of 45 lb. to get the same temperature difference.

WHAT BOILING IS.

When heat is added to a liquid, the tiny particles, called molecules, of which it is made up are put into violent movement and it is this molecular energy which is the way the heat energy is stored in the liquid. All liquids have their molecules in motion and the hotter the liquid the more violently are the molecules dashing about and colliding with each other.

Now the molecules in a gas or vapour such as air or steam are moving about much faster than those of a liquid, and the higher the pressure the more crowded together are the molecules.

At the surface of a liquid, say water, some of the liquid molecules are continually jumping out of the liquid into the air or gas or steam above the liquid, and the surface of the liquid is being bombarded with a hail of air or steam molecules. If the liquid molecules are moving with sufficient energy—that is to say, if the liquid is hot enough—the liquid molecules at the surface will overcome the hail of the steam or air molecules which are raining on to the surface, and molecules from the liquid will fly right off in a cloud whose thickness will depend on how fast heat is being added to the liquid.

The reason why a reduced pressure on the surface of a liquid causes easier boiling should now be clear. So, also, should the fact that a cool puddle will dry up on a cold day without any boiling, because some molecules at the surface will always be shooting off sufficiently fast without colliding with any air or water vapour molecules until they get entangled in the air molecules and do not return to the liquid. When the air is very damp, that is when there are a great number of water molecules dashing around with the air

molecules, the puddle does not dry up because just as many water molecules are falling from the air on to the surface of the puddle as there are liquid molecules jumping out of the liquid.

If we look at the steam table on page 92 we see the temperatures at which water would boil at different pressures above or below atmospheric pressure. We see that at quite an easily obtained vacuum the boiling point is greatly reduced. Unfortunately, when sugar is dissolved in water the boiling point of the solutions are higher than those of pure water. The higher the Brix of the sugar solution the higher is its boiling point above the corresponding boiling point of pure water. This difference between the boiling point of a sugar solution and the boiling point of pure water is called the " Boiling Point Elevation," or B.P.E., and its value changes with the temperature at which the solution is boiling. The B.P.E. of sugar solutions of various Brix and boiling under various conditions of vacuum, that is temperature, are shown in the Table VIII.

What are the practical effects of B.P.E. on the boiling of sugar liquors ? The chief disadvantage of B.P.E. to us is that for a given temperature difference across the pan or evaporator heating surface, the steam pressure will need to be higher than it would have to be for water. For example, if a liquor of 80°Bx. boiling at 20″ vacuum requires a 50°C. temperature difference across the heating surface in order to get the work done, the steam pressure will have to be 25 lb. sq. in. Had there been no B.P.E. a pressure of 16 lb. sq. in. would have given the needed temperature difference. This is of big concern to the cane and beet factories and permits them to use multiple effect evaporators of, say, only 5 effects where they could use 6 or 7 effects were the juice to boil at water boiling temperatures.

B.P.E. gives us, however, an accurate and simple way of measuring the Brix of the syrup in our pans. If we measure the temperature at which the syrup or liquor is boiling and the temperature of a little pot of boiling water attached to the pan vapour space, and therefore boiling under the same vacuum, the difference between these two temperatures is the B.P.E., and this corresponds to a certain Brix which we can read off the table on the next page. This can only be measured at all accurately on a pan with a good circulation and where the vacuum is fairly steady.

A CONSIDERATION OF BOILING POINT ELEVATION.

A few further remarks on B.P.E. may be found interesting. It is not necessary to the understanding of sugar refining to know more than that B.P.E. exists, so that those who are not interested

can skip this section.

It is not universally agreed by everyone at what temperature the water vapour comes off a solution boiling at an elevated boiling

TABLE VIII.

BOILING POINT ELEVATION OF SUGAR SOLUTIONS.

Per cent. Sugar. ° Brix.		Boiling Point Elevation °C. at Vacuum of:				
		Atmos.	15″	20″	25″	27″
10	...	·1	·1	·1	·1	·1
20	...	·3	·3	·3	·3	·2
30	...	·6	·5	·5	·5	·4
40	...	1·0	·9	·9	·8	·8
45	...	1·4	1·2	1·2	1·1	1·1
50	...	1·8	1·6	1·5	1·4	1·4
55	...	2·3	2·1	1·9	1·8	1·8
60	...	3·0	2·7	2·5	2·4	2·3
65	...	3·8	3·4	3·2	3·0	2·9
70	...	5·1	4·5	4·3	4·0	3·9
75	...	7·0	6·2	5·9	5·5	5·4
80	...	9·4	8·4	7·9	7·4	7·2
82	...	10·5	9·4	8·9	8·4	8·1
84	...	12·0	10·8	10·3	9·6	9·3
86	...	14·0	12·6	12·0	11·2	10·8
88	...	16·5	14·8	14·1	13·2	12·8
90	...	19·6	17·5	16·6	15·5	15·1
91	...	21·6	19·3	18·3	17·2	16·6
92	...	24·0	21·4	20·3	19·0	18·4
93	...	26·9	24·0	22·8	21·4	20·6
94	...	30·5	27·2	25·8	24·2	23·4

point. Professor W. L. Badger states definitely in his book, " Heat Transfer and Evaporation," 1926, page 119, that the steam comes off superheated by an amount equal to the B.P.E.

Webre and Robinson in their book "Evaporation," 1926, page 36, state that the vapour comes off superheated by an amount equal to the B.P.E. We, however, are quite sure that the vapour is not superheated but that it comes off the elevated boiling liquor at the temperature at which it would come off water boiling at the vacuum in use. Why can't the temperature be measured ? If a thermometer is put above the boiling liquor it soons gets a drop of liquor on its bulb, and this liquor will be at the elevated boiling point. If the thermometer is put so far along the vapour pipe as to be quite safe from casual drops of liquor it has always been argued that the vapour has already given up its super-heat to the vapour pipe, save-all, etc. We have got figures which we believe are accurate, and these show that the vapour comes off at the temperature corresponding to the water-boiling temperature and not at the elevated boiling temperature. Is it conceivable that a liquor boiling at, say, 65° C. can give off vapour having a temperature of, say, 55° C. ? If you find this difficult to believe, listen for a moment to the opposite story.

CONDENSATION POINT ELEVATION.

Condensation is the opposite of boiling. Boil some water at atmospheric pressure and the steam will come off at 100° C. Let this steam bubble into cold water. The steam will condense in the water and will gradually heat the water up to boiling point, 100° C., when no more condensation will take place and the steam will bubble through the water and come off uncondensed. Now bubble the steam into a strong solution of caustic soda which has an enormous B.P.E. The steam at 100° C. will condense in the caustic solution and will heat the caustic up until the caustic has been raised to its boiling point of, say, 150° C. We have actually, in the laboratory, had water boiling at 63° C. under a vacuum of 23″ and condensing its steam in a caustic solution whose temperature was 155° C. A condensation point elevation of nearly 100° C. ! If a hot solution can condense vapour much colder than itself, why should it not be able to give off vapour cooler than itself when it is boiling ? This condensation at elevated temperature is not a case of heat running "uphill." We wish it were. The hot solution will condense the cool vapour because the hot solution is below its boiling point and therefore free steam cannot exist in it. The vapour, therefore, condenses and gives up its latent heat to heat the solution (and incidentally itself). Now the hot solution must go on condensing vapour at any temperature until the solution is brought up to its boiling point. When the solution has reached its boiling point, steam can exist in it, and, in fact, the addition of any more heat to it must make steam boil off it, so that the steam we bubble into it must pass through it uncondensed and unchanged in temperature. Here is another strange state of affairs. Cool steam bubbling into

hot liquid and coming out unchanged in temperature. If the steam on its way through the hot liquor was heated up by taking heat from the solution it would bring the solution temperature down below its boiling point and condensation would start again.

Here we have two very strange facts. They are not really strange when they are examined. First a hot liquid can condense cool steam if the steam is bubbled into the liquid, so long as the liquid (which must, of course, have a high B.P.E.) is below its boiling point. Second, cool steam can bubble through a very hot liquid when the liquid is at its elevated boiling point and the steam is not heated up by the liquid. It is surely reasonable to expect that steam will come off a liquid boiling at an elevated boiling point at as low a temperature as possible. Now we have seen that steam at a low temperature can exist quite happily in a liquid at its elevated boiling point. There is really nothing very surprising that the vapour should come off the boiling liquid at the water boiling temperature and not at the elevated boiling temperature.

It may be asked whether it is not possible to use a solution with a very high B.P.E. to step up low grade heat. It is true that low grade heat can be stepped up by this means, but very little is gained because, while it is true that pan vapour can be made to make a caustic solution reach a very high elevated boiling point, all the vapour has condensed in the caustic and must be evaporated off before the caustic can be used again, and as the caustic has such a high B.P.E. this evaporation will need a very high steam pressure to do it.

GRAIN FORMATION.

It has been explained on page 41 that a supersaturated solution will throw down crystals or grain in order to return to saturation. Our object in boiling sugar liquor in a pan is to get the grain or crystals out of the solution. Some solutions, such as washing soda or alum, are not sticky or viscous at all like a sugar solution. The result is that when such a solution is thickened up by evaporation until it is supersaturated, grain will at once appear and no appreciable degree of supersaturation will be reached unless very special precautions are taken. With sugar solutions which become very sticky and thick it is possible to reach quite a high degree of supersaturation before any of the sugar crystallises out. A sugar solution will exist at quite a high supersaturation before grain appears, if the solution is kept fairly quiet. When grain does begin to appear, it does so gradually, and the solution takes a long time to return to saturation. If a supersaturated solution of soda or alum is disturbed, by a shake or by even a dust speck falling into it, the excess of solid grains out almost instantly.

In order to make the sugar grains come out of a supersaturated sugar solution it is necessary to start the graining by giving the solution a " shock." This can be done in several ways. A sudden increase in the vacuum, causing a quick flash of evaporation ; the addition of a pinch of sugar dust ; the drawing of a few bubbles of cool air through the solution. We always use the addition of sugar dust. The reason is not really to take in actual points on which the crystals can grow, because the number of points that we take in to shock the pan is much too small. The real reason that we find this the best way is probably that it gives the panman something he can see. When the grain first starts to form, the points are at first invisibly small. Far too many are usually brought in and the first thing the panman has to do is to wash most of them out as soon as they are big enough for him to see them. By using dust visible to the eye, the panman has something to watch. During his training he is taught to grow the visible grain at such a rate as to keep the invisible grain growing in the right numbers. As soon as he sees his shock grain he " checks " the pan, and this check is by long practice the right amount to ensure that neither too many nor too few of the invisible points grow.

CHECKING.

In order to prevent the throwing down of too many crystal points when the supersaturated solution has had its shock, it is necessary to reduce the supersaturation at once. There are several ways of doing this. First, the solution could be diluted with water. This is clearly a wasteful way, if there is a better one, as all the water has to be evaporated. Second, more of the liquor being boiled could be drawn into the pan. As this liquor is always kept below saturation it will dilute the very heavy liquor in the pan, and no water has been added that has not got to be evaporated anyhow. The amount of liquor in the pan is, however, increased right from the start by this way, and it becomes difficult sometimes to " bring the pan up," that is, to get a high percentage of solid sugar yielded at the end of the boiling. Third, the temperature of the liquor can be increased by reducing or " checking " the vacuum, thereby raising the boiling point. This is the method that we always use—for several reasons. It is the quickest. Immediately the vacuum is reduced, the pan goes off the boil and all the heat from the heating surface which was going into latent heat for boiling goes in sensible heat in raising the temperature of the contents of the pan. This at once brings down the supersaturation. By raising the boiling point of the sugar solution, the temperature difference across the heating surface is reduced and, therefore, the rate of heat transfer, and consequently of boiling, is reduced. Apart from reducing the supersaturation, we want to slow down the rate of boiling, as will be explained in the next section. The higher temperature also has

the effect of making the grain harder and sharper, for reasons unknown to us. Checking is, therefore, the best method of reducing the supersaturation in the pan. Sometimes some liquor—called a " drink "—is taken in at the same time.

GROWING THE GRAIN.

Once the right number of crystal points have been started in the pan it is the panman's aim that none shall be melted out and that no more shall be formed. The contents of a pan we call a " skipping "—most of the English-speaking sugar world call it a " strike." Our ideal skipping is one which, when it is finished, contains the greatest possible amount of the right sized crystals, with the fewest wrong sized crystals or " false grain," and the least amount of syrup, boiled in the shortest possible time at the highest possible vacuum.

When the skipping has just been " grained," the rate at which we can allow sugar to be thrown out of solution must be very slow indeed because the surface offered by the tiny grains is so small. If no new crystals—false grain—are to be formed, all the sugar thrown out must build itself on to these tiny points. This means that in the early stages of the skipping, the rate of evaporation must be tremendously reduced and only allowed to increase as the size of the grain increases. Otherwise the liquor will become very supersaturated, and, as it is now in a state of perpetual shock, owing to the grain in it, false grain will appear. It has been roughly calculated that just after graining we crystallise granulated sugar in a pan at the rate of about one pound in the first minute ; whereas at the very end of the skipping we are depositing it on the comparatively large crystals at the rate of nearly a ton a minute.

The speed at which a sugar crystal grows depends on the degree of supersaturation and the speed at which each crystal is moving . into contact with freshly evaporated liquor. If each crystal is always moving rapidly about, it is always moving quickly away from the little patch of liquor from which it has just taken some sugar and is coming into a new liquor patch which is highly supersaturated and on the verge of throwing out false grain. If a crystal did not quickly pass through all these patches of supersaturated liquor they would soon throw down false grain. The faster the circulation, the quicker do the crystals pick up sugar and the less chance there is of false grain being formed. The degree of supersaturation can safely be raised if the circulation can be increased. So that circulation has a manifold effect on the speed of crystallisation. Good, quick circulation is of the greatest possible importance.

We cannot say that there is any limit to the speed at which crystals of sucrose will grow except the limit imposed by circulation.

Whenever we have done anything that improves the circulation we have always found that faster crystallisation takes place. Now. in 1938, we can boil granulated sugar in half the time that we thought possible 15 years ago.

ROLLED GRAIN.

Some vacuum pans have the bad habit of making the small grain—usually when it is about caster size—" roll " together into little balls, snowflakes or conglomerates. We do not know the cause of this, but we believe it occurs when there is a temporary stoppage of the circulation. It only occurs (with a good panman) in certain pans, and it almost always happens at the same point in the skipping. Rolled grain grows as a crystalline mass and the crystals grow right through each other, just as if one had speared the other. Rolled grain cannot be separated, it is not just a bunch of crystals sticking to each other. Rolling is not always the fault of the pan. Careless boiling or the interference of another pan with the vacuum conditions may cause rolling.

Rolled grain looks ugly and, owing to its structure, does not wash up well. Sugar with rolled grain is almost always a worse colour than sugar which has a clean, sharp grain. The only way we can minimise rolling is to aim for a vigorous circulation at all stages in the boiling. (See Chapter 17, page 365)

BOILING THE SKIPPING.

A short consideration of the story of a skipping's life will be necessary before we can appreciate what characteristics a good pan should possess. Here is the story of a Plaistow granulated skipping :—

The pan has " dropped " the previous skipping and has been washed or steamed out. The bottom outlet valve is shut and the vacuum breaker is closed. If the pan is one of a number on a central condensation system, the " lifting " pump is put on to lift the vacuum of the pan to a degree somewhere near the vacuum it is going to start boiling at. If the pan were lifted by being put on to the vacuum main, all the pans on the main would suffer a temporary drop of vacuum. If the pan has its own condenser and vacuum pump it can be lifted right away by its own pump. During the lifting, the air or vapour drawn out by the pump should pass through a condenser because if there is much steam in the air its condensation will be a great help in lifting the vacuum.

While the vacuum is being lifted, a charge of liquor is drawn into the pan. This charge must be of such a size that when it is thickened up to graining point it will cover the heating surface of the pan—in

a calandria pan this means the whole of the heating surface ; in a coil pan it means the lowest 2 or 3 coils.

When the right amount of charge has been drawn in, the liquor feed valve is closed, the vacuum or vapour valve, if the pan has one, is opened, and steam is turned on to the heating surface. Evaporation of the charge now starts at a tremendous rate—in some of our big white sugar pans at the rate of over 50,000 pounds per hour for a few minutes. The rate soon falls off as the liquor gets thicker and does not circulate quite so fast. Small samples of the boiling liquor are frequently drawn out by means of the " proof cock," or " proof stick." The small sample, or " proof," of the thickening liquor is run on to the thumb and first finger of the panman's hand. By long practice he is able to recognise by the feel of the liquor when the charge has reached the correct supersaturation for graining.

This method of measuring supersaturation with the fingers may sound very rough and crude, but in practice it has shown itself to be remarkably reliable. The Micromax B.P.E. instrument which we have on some pans gives a good indication of the supersaturation and, doubtless, before long, we shall always measure the graining point by its means.

As soon as the proof shows that the liquor is sufficiently supersaturated for graining, a pound or two of sugar dust is drawn into the pan. Immediately afterwards, the vacuum is pulled down 5 to 8 inches, thus raising the temperature by some $15°$ to $25°C$. and the grain is formed as already described.

As the crystals grow or the supersaturation of the liquor rises more liquor is drawn into the pan in drinks, as and when the experience of the panman deems them to be necessary. Nowadays, with modern pans that have quick boiling properties, it is generally possible to take in most of the liquor in a continuous drink. Continuous drinking was looked upon 20 years ago as an impracticable dream, but we have been continuous drinking some of our better pans for some 15 years now.

As the grain gets bigger, so the surface upon which the sugar can grow gets larger, and so the boiling can be carried out faster, so from time to time the vacuum is raised a little. The higher vacuum not only increases the speed of boiling but lowers the boiling temperature with beneficial effects on the colour.

The constant taking in of drinks is increasing the amount of sugar in the pan, and after the appropriate time—from under an hour to some 20 hours, dependent on the material being boiled and the size of grain desired—the skipping will be finished. That is to say, it now occupies a volume such as will fill the mixer below it. If

the panman has been skilful, and if the steam pressure and vacuum have been steady, the crystals should all be of the size required and the massecuite should contain the greatest possible amount of crystal sugar and the least amount of syrup. The masse should also be at the lowest possible temperature.

The steam is shut off. If the pan is on a central condenser, the vapour valve is shut, or if on its own condenser, the water is shut off the condenser and the air valve to the vacuum pump is closed. The vacuum is broken and the pan "blown off." The bottom valve is opened and the masse is run into the mixer below.

SUPERSATURATION AT DIFFERENT STAGES.

Experience has shown us that different materials require quite different supersaturations at various stages of the skipping. The supersaturations which we have found suitable for four different qualities of material and three stages in the skipping are shown in the table on the next page. The figures represent the "supersaturation coefficient" which has the following meaning. A supersaturation coefficient of 1·2 means that a certain quantity of water has 1·2 pounds of sugar dissolved in it when 1.0 pound dissolved would be saturated. We have no exact figures of the saturation and supersaturation values of impure sugar solutions, so the figures given for crop boilings are approximate.

SUPERSATURATION AT VARIOUS STAGES OF DIFFERENT KINDS OF BOILINGS.

		Granulated Sugar.	Recovery Boilings.		
			1st Crop.	2nd Crop.	3rd Crop.
Graining	...	1 ·35	1 ·4	1 ·4	1 ·4
Growing	...	1 ·2	1 ·25	1 ·3	1 ·3
Dropping	...	1 ·1	1 ·2	1 ·35	1 ·35

YIELD.

Yield is the amount of dry sugar we obtain in one boiling from a certain amount of sugar solids in the liquor. We always express this as a percentage. That is to say, a 50% yield means that for every 100 pounds, hundredweights or tons taken into the pan as solid sugar in the liquor we got out 50 pounds, hundredweights or tons of dry crystal sugar for market. It is exceedingly important that the yield should be as high as possible. In order to get a low refinery .syrup of approximately the same analysis it would be necessary to do 5 refinery boilings if the yields were all 40% ; 4 boilings if the yields were 50% and 3 boilings only if the yields were 60%. Each time sugar is boiled, colour is made. After each boiling

the colour will probably have to be removed by char, and this entails diluting or reducing the syrup with water. Each time syrup is run over char there is some inversion and some loss. Even if the syrup is not charred it must be reduced or diluted from the super-saturated condition in which it leaves the pan to well below saturation, and all this extra water has to be evaporated. The yield that we have to worry about is not just the yield from the pan but the yield of marketable sugar. A well boiled, sharp, clean grain gives a bigger marketable yield than a rolled skipping full of false grain which showed the same yield when dropped from the pan. The fine false grain will be riddled out and much sugar will be dissolved in an attempt to wash up a rolled grain to the required colour.

The yield gradually drops all through the processes after the pan. The following comparison shows what can happen.

			YIELD.	
			Good Clean Pan.	Rolled Dirty Pan.
Yield as dropped from pan	...	...	50% gross	50% gross
After pan steamed out	...	...	48	48
After Washing in Machines	...	...	45	43
After Lump Riddle	...	...	44·5	42·5
After Dust Removal	...	...	44·5 net	42 net

FINAL TEMPERATURE.

It has already been pointed out that the saturation point of a sugar solution varies with the temperature. The higher the temperature the more sugar can a solution contain. Now at the end of the skipping there are three items in the massecuite :—crystal sugar, dissolved sugar and water. We can assume that in order to get proper crystal growth the supersaturation of the syrup at the end of the skipping is pretty well the same in all properly boiled skippings of the same liquor. But the amount of water in the supersaturated liquor will vary with the temperature. At whatever temperature a skipping is dropped, the syrup in it will be supersaturated by the same amount, and after the crystal sugar has been removed, the syrup will have to be reduced or diluted and brought to a standard temperature before it can go on to its next process. Water added at this stage has all to be evaporated later, so it is most desirable to reduce it to a minimum. The cooler the skipping is at the end of boiling the more water there is in the syrup and consequently the less water has to be added to dilute it.

Of the three items in our masse, crystal sugar, dissolved sugar and water, if we take in the same amount of syrup into the pan and get the same yield of crystal sugar we will have the same amount of

dissolved sugar. But the amount of water necessary to hold the dissolved sugar at the correct supersaturation will vary with the temperature.

TABLE IX.

BRIX OF SUGAR SOLUTIONS AT VARIOUS SUPERSATURATIONS AND TEMPERATURES.

Temperature °C.		Brix at Saturation.	Brix at Supersaturations of				
			1·1	1·2	1·3	1·4	1·5
55	...	73·5	75·4	76·9	78·5	79·5	80·6
60	...	74·6	76·4	77·9	79·3	80·4	81·5
65	...	75·7	77·4	78·9	80·2	81·3	82·4
70	...	76·8	78·5	79·9	81·1	82·2	83·2
75	...	78·0	79·6	80·9	82·1	83·2	84·2
80	...	79·2	80·7	82·0	83·2	84·1	85·1
85	...	80·4	81·9	83·1	84·2	85·1	86·0

The dropping of hot skippings can be quite wasteful, and an actual example will be worked out which requires little more arithmetic than is needed to ascertain whether 13 to 1 or 100 to 8 is the better odds.

We will take 20 tons of sugar solids in liquor at 68° Brix into our pan and we will assume that we get a yield of 50% which will give us 10 tons of crystal sugar.

$$68° \text{ Brix means 68 of sugar in 32 of water}$$
$$\text{or 20 of sugar in } \frac{32 \times 20}{68} = 9\text{·}41 \text{ tons of water.}$$

We will take two skippings each giving us 10 tons of crystal sugar but one will be dropped at 80°C. and the other at 60°C, both having the same supersaturation at the end of 1·1. From the table above we can see what the Brix of the two syrups will be at a supersaturation of 1·1 and temperatures of 80°C. and 60°C. We start with 20 tons of sugar solids and 9·41 tons of water. If we drop our first skipping at 80°C. and a supersaturation of 1·1, the table above gives the Brix of such a syrup at 80·7.

Now we must find out how much water there will be in a syrup of 80·7 Brix containing 10 tons of sugar.

$$80\text{·}7 \text{ of sugar in } 19\text{·}3 \text{ of water}$$
$$10 \text{ tons of sugar in } \frac{19\text{·}3 \times 10}{80\text{·}7} = 2\text{·}392 \text{ tons of water.}$$

The syrup which was taken into the pan contained 9·41 tons of water so that in this case 7·018 tons of water have been evaporated.

If the skipping is dropped at 60°C. we see from the table that a solution having a supersaturation of 1.1 will have a Brix of 76 ·4.

76 ·4 of sugar in 23 ·6 of water

$$10 \text{ tons of sugar in } \frac{23 \cdot 6 \times 10}{76 \cdot 4} = 3 \cdot 09 \text{ tons of water.}$$

The syrup taken into the pan also contained 9 ·41 tons of water, so that 6 ·32 tons of water have been evaporated.

In both these cases the syrups contained 10 tons of sugar, but in the case of the skipping which was dropped cooler the evaporation was 10% less than the skipping which was dropped hot. Both syrups have to be reduced or diluted to the same Brix for subsequent treatment. Nearly half a ton more water will need to be added to the one than to the other, and this water will all have to be evaporated in the next boiling.

What happens during the life of the skipping can have no effect on the amount of evaporation—unless water drinks are taken in—the only thing that matters from the evaporation point of view is the temperature, or vacuum, at which the pan is dropped.

A cool skipping is not very much more sticky and viscous than a hot one. This is because the supersaturation is the same in either case, which means that there is less sugar in solution in the cool skipping so that its stickiness will be hardly more than that of hot syrup containing more sugar to be at the same degree of supersaturation. The stickiness or viscosity varies fairly closely with the temperature, just as the supersaturation does. Over the ordinary range of temperatures that we use in our pans, the degree of saturation or supersaturation corresponds pretty well with a particular viscosity or stickiness. This is the reason why the panman can use his fingers as a measure of supersaturation. Because the stickiness that he feels with his finger and thumb when taking a proof goes pretty well with the supersaturation and is within practical limits almost independent of temperature.

VERY HIGH YIELD.

During 1935, we tried to get exceedingly high yields from one of our fine sugar pans—yields in the neighbourhood of 70%—something quite unheard of. Before success was achieved, a good many alterations had to be done to the pan. The tubular calandria had to be replaced by a ribbon calandria, an extra large discharge valve had to be fitted to the bottom of the pan and a spray pipe had to be fitted

inside the top of the pan. There was then no difficulty in getting yields that had previously been dreams. The method is to boil an ordinary skipping and when it is " finished " go on boiling for another 15 minutes or so. It required considerable courage to do this as the skipping looks as if it would have to be dug out. It is difficult to tell the end point from proofs, but quite easy by looking into the top of the pan.

The real difficulty in getting high yields has been that the traditional apparatus was entirely unsuitable. A high yield masse cannot run out through a tubular calandria. After a core has run down the central downtake, the rest of the skipping just lies on the top tube plate. The ribbon calandria solved this problem. The area of holes in a tubular calandria is about 30% of the area of the pan, whereas the area of the spaces between ribbon heating elements is about 70% of the area of the pan. It was found to be of great assistance to help the skipping out of the pan with " lubricating " syrup. This is saturated syrup from the previous skipping which lubricates the heavy massecuite without diluting it and enables it to run out of the pan and into the centrifugal machines. This lubrication syrup is put in through a spray pipe round the top of the pan and we have found that this syrup washes all the grain out of the pan and eliminates the necessity for steaming out which previously caused a considerable reduction in net yield by dissolving some of the grain.

COMPARISON OF GOOD AND BAD YIELDS.

	Low Yield. Plaistow, 1936	High Yield. Plaistow, 1939
Solids In	100	100
Sugar Out	94	94
Average Yield of all Boilings ...	42·2%	62·1%
Yield of First Boiling	45%	63%
Number of Boilings	5·6	3
Massecuite Solids Boiled	222·44	151·4
Average Ash of Masses	·225%	·179%
Average Ash of Heavy Syrups ...	·399%	·472%
Water Evaporated	82·17	60·87

It will be seen that the high yield shows benefit in every respect except one—namely, that the syrup to be washed off the crystals has, on average, a worse analysis, which means that more wash water will be required than would otherwise have been necessary, which makes the yield a little lower than it might have been.

SURFACE BOILING.

Liquor or syrup in a pan only boils near the surface unless the

circulation is very bad, because the massecuite below the surface is not only under whatever pressure the vacuum in use corresponds to but under the pressure of the weight of the massecuite above it. It therefore has to be hotter than the surface masse before it can boil. Three feet of massecuite is equivalent in pressure to four inches of mercury. If a pan is boiling under a vacuum of 24″, the surface will be boiling at the temperature appropriate to the vacuum, whereas the masse three feet below the surface will have a boiling point corresponding to a vacuum of 20″—that is, some 10°C. higher. It is possible for the lower parts of the massecuite to get very much overheated if there is a sluggish circulation. If the circulation is good, the masse that may have got too hot quickly comes near the surface where it at once flashes off its heat into steam. Here is another reason for making the circulation as vigorous as possible.

GENERAL PAN DESIGN CONSIDERATIONS.

We have gone briefly over the most important theory and practice of sugar boiling and are in a position to say that certain qualities are essential for a good pan. At almost every point in the consideration of sugar boiling, the desirability of having a good circulation has been prominent. Good circulation prevents local excessive supersaturation which might cause the throwing down of false grain. Good circulation is conducive to getting a sharp, clean grain without rolling. Good circulation prevents local overheating low down in the pan with possible colour formation.

Another important quality is an ability to start the pan with a small charge. This makes it much easier to bring the pan up to a heavy yield. There are always the same number of crystal points in similar skippings in similar pans. If these points are closely packed into a small charge it is a simple matter to drink the masse so as to keep it tight. If, on the other hand, the charge is large, the grains are swimming about in a lot of liquor and it is difficult to make the liquor reduce itself by crystallisation without making false grain. Unless the bulk of the liquor can be reduced by depositing sugar on the crystals in the fairly early stages of the pan, the panman finds that he has a pan full of liquor which is well supersaturated long before he has grown his grain to sufficient size. He then has to try to grow from what he has in the pan without taking in drinks, a rather ticklish thing to do. The smaller the desired grain, the larger can the charge be. The present tendency, and it has been operating for at least twenty years, is towards smaller and smaller crystals in the standard market sugars. This enables us to use calandria pans for granulated. Or did we use calandria pans for granulated and persuade the public to like a smaller grain ?

Another important quality in a pan is an inside free from

obstructions so that a heavy skipping can be run out easily and quickly, and so that the empty pan can be easily and economically washed out with the minimum of saturated syrup without the need to use steam or sweet water.

Apart from sugar boiling considerations there are many engineering qualities that many years of suffering with all sorts of pans have taught us.

Pan design is still to a great extent a matter of personal opinion, and a large element of luck appears to attend the performance of any particular design. The only way to find out the benefits or short-comings of any pan design is to make one and try it.

GENERAL DESCRIPTION OF VACUUM PAN.

The vacuum pan was invented by Howard, in 1813. It is a large metal vessel, strong enough to resist collapse when subjected to high vacuum. Nowadays, pans are generally cylindrical in shape with the bottom made conical, or sloping, to assist the running off of the massecuite. The diameter of our smallest pans is about 9 feet, and of the largest, about 18 feet. The height is generally between one-and-a-half and three times the diameter. In order to aid circulation and to minimise the risk of the lower parts of the masse getting overheated, we consider it good practice to make the full skipping not more than the pan diameter in height. Our big white sugar pans drop a skipping of about 60 tons of massecuite. If the yield was about 63% this means that from the skipping we shall get 38 tons of dry sugar.

The heating surface of the pan into which the steam is fed can either be in the form of coils with the steam inside them, or what is called a calandria, which is a drum with tubes running from the ends or tube plates. In this case, the massecuite is in the tubes and the steam is inside the drum on the outside of the tubes. If coils are used they can fill the whole of the skipping space of the pan and steam can be turned on to each coil in turn as the skipping mounts up the pan. If a calandria is used, it is placed low down in the pan, as it must be wholly covered all the time.

At the top of the pan, a " save-all " of some sort must be provided to catch any drops of syrup carried over with the vapour. The top of the save-all is connected either to the pan's own condenser or through a vapour valve to the vapour pipe which leads to a central condenser.

Small windows, or " eyeglasses," are placed in a continuous row up the side of the pan to enable the panman to see how far up his skipping has reached and how vigorously it is boiling.

MECHANICAL CONSTRUCTION OF PAN.

Electrical welding has made a great difference to pan design, construction and maintenance. Before the days of welding, the pan body was made up of plates or rings that were bolted or riveted together, and the joints gave perpetual trouble. Air leaks into the body of the pan lowered the vacuum and tended to make false grain if the leak was below skipping level. The joints on the coils and calandria constantly leaked steam as did, also, the ends of the calandria tubes where they were expanded into the tube plates. These steam leaks were not only wasteful of steam, but, when the pan was blown off and the steam turned off, the steam inside the heating surface condensed and formed a vacuum inside which sucked the syrup into the coil or calandria. This caused the condensed water to become sweet, which made it useless for certain purposes such as boiler feed.

For a quick boiling granulated pan it is impossible to get the heating surface necessary with coils, and a calandria appears to boil a better, cleaner grain. But for low molasses boilings, where the rate of evaporation has to be very low, it has not yet been conclusively proved that a calandria is any better than coils.

Most calandrias are the same diameter as the pan—the shell of the calandria being the lower part of the shell of the pan. Some of our earlier calandrias were two or three feet smaller in diameter than the pan, and are called floating calandrias. Pans with floating calandrias have given very good service, and we disapprove of them purely on theoretical grounds because the circulation is not definite, that is to say we do not know whether the masse does or should move up or down in the space between the calandria and the pan shell. When calandrias were first made—and to-day in the U.S.A. (we consider we are 15 years ahead of the Americans in pan design)—the tubes were of copper and were expanded into bronze tube plates. For many years now we have used steel tubes welded into steel tube plates, and the steam leakage which was the bugbear of the old calandrias has disappeared entirely. A steel calandria only costs about one-third of the price of a copper and bronze one. Steel, of course, is not such a good conductor of heat as copper, which means that with a steel calandria we need a greater temperature difference between steam and massecuite, and this calls for higher steam pressures. This is of no real consequence. No more heat is used in the one case than in the other. In order to get the higher process pressure, we have to use a higher back pressure on the turbine, which means that for the same electrical output more steam must pass through it and, consequently, less steam will pass through the reducing valve from high to low press main.

The centre of the calandria is a large tube, 3 to 5 feet in diameter. The heated masse rises in the tubes and returns down the centre tube or downtake. A similar downtake is provided in a coil pan.

RIBBON CALANDRIA.

The ribbon calandria—either in the form of circular ribbon elements (the Grāntzdörffer design) or in the spiral or scroll elements (the T. & L. design) has certain great attractions, and we have had excellent results from it. For a given heating surface it offers much less resistance to circulation, and it is the only type of heating surface that will allow a very high yield skipping to run out of the pan.

The ribbons are made up of two plates about three feet deep and two inches apart. The edges of the plates are bent over towards each other and welded together. The length of each ribbon may be as much as 30 feet. The Grāntzdörffer ribbons are circular. When the ring ribbons are welded to their steam pipes there are a number of quite inaccessible parts which cannot be reached for repair should a leak make its appearance.

The spiral ribbon enables repairs to be effected. The spiral element is bolted into the pan with two joints. The top large steam inlet is bolted to the steam belt round the outside of the pan, and the bottom small water outlet, which is made at the inner end of the spiral, is bolted to the false bottom of the pan in which the condensed water from ribbons and jacket collects and is led to the trap. The spiral elements are all interchangeable, identical units, and they are spaced symmetrically round the pan. The two joints are disadvantages to be set against the other great advantages (since we have been using all-welded pans we have also learnt how to make tight steam joints !).

When the masse is running out of the spiral ribbon pan it can not only run down between the ribbons but also run spirally into the centre of the pan. The bottom of each spiral is shaped to follow the angle of the bottom of the pan, and this slope lets the condensed water run away easily.

AIDS TO CIRCULATION.

We do not really know what are the qualities in a pan which make for good circulation. Some pans have good circulation ; others, for no apparent reason, fail completely and lie stagnant. Others circulate well except at one particular level in the skipping.

We believe that for a particular rate of boiling, that is for a particular rate of heat transfer, the circulation is better with a large temperature difference through a small heating surface than when

the heating surface is large and the temperature difference is small. We believe that the height of a skipping should not exceed its diameter. We believe that the slope or angle on the pan bottom should be as flat as possible, lest a big dead space lie stagnant above the outlet valve. We believe that the drinking pipe should feed into a large diameter perforated or slotted ring pipe so as to give the drink every chance to mix with the masse before it reaches the top of the skipping where it will prefer to stay owing to its lighter weight. We believe that the central hole down the heating surface should be as large as possible. As regards the shape of the pan, we have never been able to prove that the plain cylindrical shape is any worse than the turnip shape, although the turnip would appear to be the shape most encouraging to an easy circulation. The only shape that we have proved to be a complete failure was a pan with a very steep bottom slope—it looked like a top—and had a short and shady career in the recovery house, at Plaistow.

ARTIFICIAL CIRCULATION.

A large propeller in the middle of the pan would seem to be a good idea. A number of pans are working (1938) in America with motor-driven impellers, and their owners are enthusiastic about their performance. We tried one of these impellers in a recovery pan where we were advised that 75 H.P. would be sufficient to drive it. We found that 120 H.P. was needed some time before we were ready to drop the skipping. We bring our pans up tighter than the Americans, and would need much more power than we are prepared to allow. No impeller could be made stout enough to move a really high yield white sugar masse, and the horsepower, were such a thing tried, might need to be some 1,000. We found that it was very difficult to get anything but a very small grain. The impeller also seemed to be the maker of a lot of false grain.

GAS REMOVAL.

Water can dissolve quite an appreciable amount of air. When the water is turned into steam in the boiler any air or dissolved gas is given off too. At high temperatures, these gases may be very corrosive, so an endeavour is made to remove the dissolved gases from the water by means of a deaerator—page 116—before the water enters the boiler. Some little gas always exists in steam.

When steam is fed into the coils or calandria of a pan it gives up its heat and condenses. But any gas present cannot condense. The condensed water is removed from the heating element by means of some kind of trap—page 95—but any gas will stay behind and would gradually accumulate until it filled the coil or calandria, when no steam could get in and all heat transfer would stop. Means must,

therefore, be provided for continually removing such gas.   In T. & L. pans, a small pipe is led from the end of each coil or from several places on the inner part of the calandria furthest from the steam inlet and led to the outside of the pan where they are provided with a small valve, or cock, and allowed to blow continually a small amount to atmosphere.

If the pan trap has a small pipe connected from its top into a lower pressure line, the calandria vents can be entirely dispensed with. The gas is swept out of the calandria by the steam into the trap, whence it blows into the lower pressure line.   Of course, this means that it must be got rid of from the low pressure line, but the low pressure plant would have to be vented anyhow.

CONDENSED   WATER   REMOVAL.

When the steam gives up its latent heat to the heating surface it condenses into water.   Unless some means were provided for taking away this water, the coil or calandria would soon get filled with water and no steam would enter and the pan would stop boiling.   The water is removed by an apparatus called a " trap "— page 95.

Traps are expensive and require upkeep, and as the modern efficient traps that we use, operated by hydraulic power, are delicate pieces of apparatus, we try as far as possible to reduce their number to a minimum.   T. & L. are now adopting the arrangement of using one big trap for all the plant in one department.   For example, all the pans in the Plaistow Wharf pan house lead into one big trap. Each calandria has its own " tail-pipe," leading direct from the calandria right down into the trap, quite separate from the others. This arrangement enables the various calandrias to carry different steam pressures without interfering one with another.

In the Plaistow Wharf pan house, the common trap taking the condensed water away from all the pans is 130 feet below the pan calandrias, and each calandria is connected to the trap by its own separate tail pipe.   Now if one pan has 70 lb. steam pressure on its calandria there will be 70 lb. pressure in the trap, and if another pan has the steam on its calandria checked down to 60 lb., water will stand up in the tail pipe of that pan so that its height will equal the 10 lb. pressure difference.   If the table on page 40 be looked at it will be seen that this 10 lb. pressure will correspond to a height of water up the pipe of about 23 feet.   So that while the pressure in the calandria can be 60 lb., the pressure on the trap is this 60 lb. plus the 23 feet of water which is 10 lb., which balances the 70 lb. which is the pressure from the other pan.

The lowest pressure which this arrangement permits any

calandria to use is found by subtracting the pressure which the highest water column can exert from the highest steam pressure that can be put on to any calandria. In the case of the Plaistow Wharf pan house, the water column of 130 feet can exert a pressure of 60 lb., and the maximum steam pressure which is available for the pan calandrias is 70 lb., so that the lowest pressure that any calandria can work at is 10 lb. sq. in.

SAVE-ALL.

When the liquor in a pan is boiling vigorously, and particularly at the end of a very high yield skipping, splashes are thrown up a long way above the surface of the boiling massecuite. These must be caught lest they get carried into the condenser and get lost in the river water. All sorts of complicated baffles and separators have been tried, but by far the simplest and most effective is to carry the pan up in full diameter a long way above the skipping. In this big diameter the vapour is going at its slowest and is therefore exerting the least drag on the splashes. Also gravity is acting in the opposite way to the vapour, and is therefore at its most efficient in helping to prevent the vapour pulling the drops along. Any form of baffle save-all means much restricted vapour spaces with correspondingly increased vapour speeds necessitating increased condenser and vacuum pump power. We have found that if we make a pan with a vapour space equal to the skipping space that we get no " entrainment," as the carrying over of splashes is called.

All save-alls work on one simple general principle—namely, that of making the vapour move in a curve or round sharp corners so that the drops of liquor will go straight on and strike a baffle plate where they can be collected and returned to the pan.

ACTION OF CONDENSER.

It is the condensing of the steam or vapour boiled off the liquor that maintains the vacuum under which the pan is boiling. Let us be quite sure that this is quite clear ; but first, the type of condenser that we use will be briefly described.

The condenser is a vertical cylindrical vessel made of cast iron to resist the corrosion of the river water. It is generally about 2 or 3 times as high as its diameter. Its diameter is generally from one-third to one-half of the diameter of the pan to which it is connected. The vapour from the pan enters the condenser through a hole, almost equal in size to the diameter of the condenser, on one side of the bottom of the condenser. Cold water is sprayed into the top of the condenser and arrangements are made for allowing this water to get away from the bottom of the condenser. A pipe from the top of the

condenser leads to the vacuum pump whose purpose will be described
in a few moments.   The water can be supplied to the condenser
through spraying nozzles spaced symmetrically round the top part
of the condenser, or the water can come in through one large inlet
and pass in a series of curtains over baffles or shelves in the condenser.
Rather surprisingly, measurements of temperature and vacuum
indicate that the shelf type of condenser is rather more efficient, that
is to say uses less water, than the spray type.   The technical name
for this type of condenser, whether baffle or spray, is the " baro-
metric jet condenser."

Let us pay an imaginary visit to the inside of one of the con-
densers attached to one of the big granulated pans in the Plaistow
Wharf pan house.   We shall be properly surprised at the turmoil.
Cold river water is pouring through in a nightmare rain at the rate
of about three tons a minute.   Hot vapour is rushing in at the bottom
of the condenser to meet the cold water at about 300 miles an hour.
Now a pound of vapour at 26″ of vacuum occupies 180 cubic feet, and
can be condensed by about 15 pounds of river water which occupy,
with the condensed vapour, about $\frac{1}{4}$ cubic foot.   This 700-fold
contraction of volume is what causes the vacuum under which we
boil the pan.

Now suppose the amount of water entering the condenser is
reduced, the first immediate effect is that there will be too much
vapour which will at once reduce the vacuum.   This will increase
the boiling temperature which will also increase the vapour tempera-
ture in the condenser.   This will permit each pound of river water to
condense rather more vapour than before, as the temperature of the
water leaving the condenser will be higher.   The condenser will
settle down to the new conditions where, say, 12 pounds of river
water are condensing one pound of vapour.   This corresponds to a
vacuum of 24″.   Now each pound of vapour at 24″ occupies 120
cubic feet, and will become, with the condensed vapour, 13 pounds
occupying $\frac{1}{5}$ cubic foot.   This is a 600-fold contraction in volume
which accounts for the lower vacuum.

Let us try to do a calculation to see what the difference in the
amount of evaporation and in consumption of river water will be.
(The reader is warned that this calculation is not strictly correct
and is only given as a rough illustration).

Assume the pan to be near its graining point at a supersaturation
of about 1 ·3 and a Brix of 79°.   It will have a B.P.E. of about 7°C.
So that at 26″ vacuum it will be boiling at 52+7°C.   If the steam in
the calandria is at 70 lb. pressure, its temperature will be 158°C. so
that the difference across the heating surface will be 99°C.   Now, by
cutting down the water so that the vacuum has risen from 26″ to 24″

the boiling temperature will have gone up from 52+7°C. to 61+7°C. or 68°C. The temperature difference across the surface will be 90°C. instead of 99°C. The evaporation will therefore drop proportionately. If the pan had been evaporating at the rate of 27,000 lbs. vapour per hour, this would fall to about 24,400 lbs. per hour, or some 407 lbs. per minute.

Each pound of vapour will need 12 pounds of river water to condense it, so that 407 pounds of vapour will need about $2\frac{1}{6}$ tons of river water per minute instead of three tons at 26″.

If, therefore, we want to check the evaporation by 10%, or check the vacuum from 26″ to 24″, it will be necessary to shut the valve controlling the river water to the condenser by such an amount as will reduce the flow from 3 tons a minute to $2\frac{1}{6}$ tons. (The mistake in this calculation is the assumption that the rate of evaporation is exactly proportional to the temperature difference across the heating surface. Two things prevent this exact proportion ruling. First, the higher the temperature at which the heat transfer takes place the faster is the rate of transfer. Second, the faster the evaporation, the faster will be the heat transfer. As these factors are mutually interlocked, the exact calculation becomes rather complex. But the foregoing calculation is quite near enough for practical purposes.)

TABLE X.

CONDENSER WATER.

POUNDS OF RIVER WATER PER POUND OF VAPOUR.

Vapour Temperature.	Condenser Water at Vapour Temperature.	Condenser Water 5°C. below vapour.
38°C.	25	29
52	15	18
61	12	14
72	10	11

WATER NEEDED BY CONDENSER.

If the condenser is so designed that the water raining through will all get a chance of condensing vapour, it should be possible for the water to leave the condenser at the same temperature as the vapour. The only heat transfer that has taken place in the con-

denser will then have been that of the latent heat from the vapour to the water.   Quite a number of our condensers are so efficient that ordinary thermometers cannot detect any temperature drop between the vapour entering the condenser and the water leaving it.   The more efficient the condenser, the less water is used.

NEED FOR VACUUM PUMP.

We have been assuming, so far, that the vapour from the pan consists of steam only and that water only is added to the condenser.

In practice, air leaks into the pan through the proof stick hole and through the bottom valve of the pan.   There is also always some air dissolved in the liquor.   If this air were not removed, the top of the pan would soon fill with air and the way for the vapour into the condenser would be blocked and, finally, the condenser would fill up with air and condensation would stop, so that the pan would cease to be boiling under a vacuum.   It is therefore necessary to have some means whereby any air in the system is continually withdrawn.   One of the biggest sources of air is the air dissolved in the river water.   In an efficient condenser, the water leaves practically at its boiling point at the vacuum in the condenser, so that any dissolved air is given off.

VACUUM PUMP EQUILIBRIUM.

In order that the vacuum pump may draw air out of the condenser, there must clearly be a greater vacuum at the pump suction than in the condenser.   But as the pump tries to increase the condenser vacuum it will just draw some vapour.   The pump cannot appreciably affect the vacuum by drawing vapour because the displacement of the pump pistons is, say, 1,700 cubic feet per minute, whereas 27,000 pounds of vapour per hour at 26″ vacuum is a flow of 81,000 cubic feet per minute.   So that the pressure difference urging the air into the pump must always be very small, and, for this reason, it is necessary to have a pump very much bigger in capacity than the amount of air that has to be pumped.

If the water to the condenser is checked in order to lower the vacuum, the vacuum pump will still try to maintain the vacuum and will draw vapour in such a quantity as to kill the excess suction that it is giving.   For any vacuum below the highest that the combined system of condenser and pump can give, a checking of the condenser water will always give the desired vacuum, and the excess vacuum that the pump is trying to give will be automatically corrected by vapour.

TEMPERATURE OF CONDENSER.

If the condenser is of reasonably good design, the water leaving

it should be not more than 2°C. below the temperature of the vapour entering it. If the condenser is adequate and the vacuum pump is big enough, then the condenser temperature at the bottom will be the vapour temperature corresponding to the vacuum in the system. The air pipe leading from the condenser to the vacuum pump should always be warm because there must always be some vapour drawn over by the vacuum pump if it has a margin as already explained. The only time that the air pipe can be cold is if the vacuum pump is fully loaded when pump capacity will be limiting the vacuum.

The condition occasionally occurs which is known as a " frozen " condenser. This is due to too much water being passed through the condenser. This gives off more air than the pump can deal with. The vacuum then drops, the evaporation slows, the vapour is easily condensed but the pump cannot clear the air away, and the condenser gets quite cold because there is a great excess of water for the diminishing evaporation, yet the vacuum is low.

CENTRAL OR SEPARATE CONDENSERS.

It is ideal for each pan to have its own condenser and vacuum pump. One pan cannot then interfere with another. The amount of water is much less than with a central condenser. Separate condensers and pumps are very expensive.

In a central condensation system, the pan vapour outlets are all connected through big vapour or vacuum valves to a vapour main which leads to a large single condenser to which is attached one large vacuum pump. This is very much cheaper and simpler, but when one pan goes on or off the system it always affects the vacuum on the others to some extent. The central condenser uses a great amount of water because the condenser must not only always be kept at the highest vacuum that any pan may want but must be kept at a vacuum an inch or so higher than the vacuum needed by any pan in order to allow for vacuum drop along the pipe.

With a central condenser, the vacuum on an individual pan is controlled by the vapour valve which is a quicker and easier way than by reducing the amount of water going to the condenser.

When a central condenser is used, it is necessary to have a small auxiliary vacuum pump, called a " lifting pump," to lift the vacuum on a pan before it can be put on to the vapour main. Impatience on the part of the panman, if the lifting is progressing slowly, is one of the great troubles of a central condensation system, as pans are often put on to the main before they are properly lifted, and this pulls down the vacuum on the whole system.

SURFACE CONDENSERS.

A surface condenser is a vessel something like the calandria of a pan (actually, a calandria is a surface condenser on whose surface the steam used for boiling condenses). In a surface condenser, the cooling water passes through the tubes and the vapour goes into the spaces around them. The surface condenser must have a temperature difference across the surface of the tubes in order that the heat can flow through the metal from the vapour into the water. This means that the water must always be well below vapour temperature, which, of course, means that more water must be used. If water is easy to come by the condenser can be made smaller and the temperature difference can be larger. This is important because a surface condenser is a very expensive piece of plant.

There are certain big advantages that a surface condenser possesses that a jet condenser has not got. First, in a surface condenser all the condensed vapour is recovered as distilled water. Second, as the only air in the condenser is that due to leakage or that which comes out of the liquor being boiled, the vacuum pump can be very much smaller than that needed for a jet condenser. Third, due to the second advantage, the vacuum that can be obtained with a surface condenser is much higher than can be obtained at all reasonably with a jet condenser.

The disadvantages of a surface condenser are : First, its large first cost. Second, that its tubes require frequent cleaning. Third, that the tubes are very likely to leak at the tube plates, especially with the big fluctuations in temperature that a condenser attached to a vacuum pan is subjected to. The condenser temperature may change from 15°C. to 80°C. within an hour.

The power stations all use surface condensers because by their means all the water can be recovered as clean, distilled water. A higher vacuum can be obtained and a power station wants the highest possible vacuum. The power station surface condenser works the whole week with hardly a degree of temperature change and, consequently, its tubes are less likely to spring leaks.

It is possible that in the future we may learn how to boil pans at very high vacuum which will be very beneficial as regards colour-making, and we may use surface condensers one day. We had one years ago at the Plaistow Wharf recovery house, and were all delighted to see the last of it. It gave constant trouble.

We use now, and have used for 30 years, small surface condensers for heating all the town water that we are going to use hot. We are thus able to heat all our boiler water and the town water that goes to wash chars from cold up to about 55°C. for nothing, with heat

that would otherwise go into the river.

ATMOSPHERIC PIPE.

The river water that is used for condensing must be continually removed from the condenser. If the condenser is near the ground, the water would have to be sucked out with a pump. If the condenser can be arranged 35 feet or more above ground, the water will run out of the condenser by its own weight. The air exerts a sufficient pressure to hold up a column of mercury 30 inches high. Mercury is about 14 times as heavy as water, so that the atmosphere can hold up a water column 35 feet high if there is a perfect vacuum above it. If, therefore, a pipe is led out of the bottom of the condenser and made 35 feet long with its lower end dipping into a tank which is kept full of water by its outlet being an overflow, then, however good a vacuum is raised in the condenser, the pipe can never fill right up into the condenser, and water can be poured from the condenser into the top of this pipe and it must displace water out of the bottom into the " atmospheric " tank which then overflows. The pipe and tank are called " atmospheric " because the water inside the pipe is held up by the pressure of the atmosphere on the surface of the water in the tank. The arrangement is identical with the mercury barometer described on page 189.

The atmospheric tank must be large enough so that when the vacuum pump lifts the vacuum before the water has been turned on to the condenser, the atmospheric pipe can fill right up. Otherwise, if there were insufficient water in the tank for this, air would be drawn into the bottom of the pipe and the vacuum would be broken.

CLEANING OUT THE PAN.

After each skipping, all the grain must be cleaned out of the pan, or each skipping would start with some large crystals which would grow into much larger grain than the size intended. The quickest and easiest way of cleaning the pan is to turn steam into it. But this steam adds water to the syrup and dissolves grain that has been laboriously made. It has recently been found that the pan can be cleaned out completely with saturated syrup from a previous skipping. As we need to lubricate high yield masses with saturated syrup, this can be used to wash the pan.

The only advantage that steaming out has is that the vacuum pump has not got a whole panful of air to deal with when lifting, as the pan is full of steam which can be condensed.

SCALE.

All sugar liquors contain some metallic salts (Ash) and during

the concentration that takes place during crystallisation of the sugar, some of these salts are deposited as a scale on the heating surface. If this were allowed to grow at all thick it would prevent the heat passing through from the steam to the masse. The scale consists chiefly of calcium carbonate, calcium phosphate and calcium sulphate. It is easily dissolved by means of very dilute hydrochloric acid which does not attack the steel of the pan. This acid washing has to be done every month or so. But surprising results have been obtained from the ribbon calandrias in the new Plaistow Wharf pan house, which have run two years without any sign of scale. Presumably, the circulation is so good that the scale is scoured off as it forms.

PAN ACCESSORIES.

Each pan is fitted with a vacuum gauge and a thermometer on the body of the pan. A steam pressure gauge is connected to the heating element. Glass windows, or " eyeglasses," are fitted all the way up to enable the level of the skipping and the violence of the boiling to be seen. To enable " proofs " to be drawn from the pan, a proof-cock, or proof-stick, sometimes both, are fitted. The proof-stick is a brass rod with a handle at the end which can be slid in and out of the boiling masse. In one place, near the end of the stick, is a little recess, or dimple. When the stick is pulled out, the dimple contains a small sample.

The bottom valve on pans designed to boil high yield skippings is so large that it is necessary to operate it by means of a motor. The motor driving the valve has an overload release which cuts out the motor circuit when the current rises to much over full load. The motor is switched on to shut the valve, and when it is shut the motor is pulled up, taking a big rush of current which trips the release. Some of our pans are fitted with hydraulically worked bottom valves.

The various devices, boiling point elevation meters, conductivity meters, pan refractometers, etc., intended to help the panman to boil more consistently, will not be described. They are still experimental and would take more space than their general interest warrants.

CHAPTER II. EVAPORATORS.

And while the bubbling and loud-hissing urn
Throws up a steamy column.

<div align="right">COWPER—The Task—1785.</div>

Similarity of Evaporators and Pans—Batch or Continuous Operation—Stand-
ard Calandria Evaporators —Film Evaporators—The Lillie Film Evaporator—
The Kestner Climbing Film Evaporator—Self-Evaporation—Multiple Effect
Evaporation — Multiple Effect Water Still — Multiple Effect Sugar Liquor
Evaporation.

SIMILARITY OF EVAPORATORS AND PANS.

A vacuum pan is a piece of plant for boiling water off sugar
solutions and carrying the concentration to such an extent that
crystal sugar is thrown out of solution.   If the concentration is less,
and is carried out only to " thicken up " the liquor or syrup, then the
piece of plant for doing this is called an evaporator. There are many
different types of evaporator, but they all comprise the essential
features of a vacuum pan, namely, a tubular heating surface having
a vapour space above it which is connected to a condenser and
vacuum pump.

BATCH OR CONTINUOUS OPERATION.

A vacuum pan works on batches or skippings. No way has
been yet discovered of graining at one part of a pan and drawing off
full sized crystals from some other part.   While evaporators are
occasionally worked on batches, one of the advantages possessed by
an evaporator over a pan is its ability to operate continuously.
Batch operation always means that the liquor must have been
longer in the heat than it would have been had the operation been
continuous. Continuous operation requires the feed arrangements to
be steady and easily controlled, and it also demands a very accurate
draw-off, or " extraction," of the thickened liquor at the correct
Brix.

STANDARD CALANDRIA EVAPORATORS.

By far the most commonly used evaporators are what are known
as standard calandrias.   These evaporators are generally similar in
all respects to a calandria pan.   There are a few detail changes. The
tubes are generally of much smaller diameter and may be as much

<div align="center">231</div>

as two or three times as long.   In this type of evaporator, the feed
can be controlled by some float valve arrangement, or by a device ·
similar to a boiler feed regulator (see page 113).   The drawing off, or
extraction, is done either by means of a pump or by means of an
atmospheric tank, or " barometric leg."   This calandria type of
evaporator is simple to make, maintain and operate, but it contains a
lot of liquor which means that the liquor must be a long time in
contact with the heating surface.

FILM EVAPORATORS.

These have nothing to do with the pictures ! The heating surface
in a film evaporator is above liquor level and is not submerged as is
that of a calandria evaporator.   Various ways are adopted to cause
the liquor to flow over the heating surface in a very thin film.   By
this means, the evaporation is done on a very small quantity of
liquor at a time which means that this small quantity will only be
in contact with the heating surface for a very short time.   A film
evaporator only contains at any one time a small fraction of the
liquor that a calandria vessel holds.   Film evaporators were a great
boon to many industries apart from the sugar industry.   Milk, and
other easily damaged food products, which could not stand the long
stewing that they received in a calandria vessel, can now be easily
thickened up.   Raw sugar factories seldom use film evaporators.
First cost is very important to a plant which is only going to work a
small part of the year.   For liquors that contain invert, such as
goldie, film evaporators are of great use.   The goldie is inside our
Kestner film evaporator for less than three minutes.   If we had to
use an evaporator with a submerged heating surface, it would
probably be necessary to keep the goldie in contact with the heating
surface for at least 20 minutes. · Many different kinds of film
evaporator have been invented, but they can be divided into two
classes : those with artificial circulation and those with natural
circulation.   Only two kinds will be described—one of each type.

THE LILLIE FILM EVAPORATOR.

The Lillie evaporator consists of a horizontal cylindrical vessel
almost entirely filled with almost horizontal tubes.   The vessel is
kept empty, and steam is supplied to the inside of the tubes.   The
liquor being evaporated is sprayed on to the topmost tubes and then
runs zig-zag down over the other tubes in a thin film, and finally runs
into a sump in the bottom of the casing of the vessel.   A circulating
pump draws off from this sump and pumps the liquor round through
the sprays.   Another smaller pump is connected to the sump to
extract the concentrated liquor.   The amount of liquor drawn off
by the extraction pump when the evaporator is working must be
adjusted to keep the extracted liquor at the right Brix.   If the Brix

goes up, more liquor must be drawn out. Conversely, if the Brix goes down, less liquor must be extracted. The sump at the bottom of the vessel is provided with a gauge glass so that the level of the liquor in the sump may be seen. By this means the feed of thin liquor into the vessel can be regulated to keep the right amount of liquor in the sump. If the sump were to be drawn empty by the extraction pump, there would then be no liquor for the circulating pump to spray over the tubes, and the vessel would stop evaporating and the liquor on the tubes would be burnt. If the sump were allowed to fill up and the liquor level to rise in the vessel, the plant would cease to act as a film evaporator and would act as a submerged heating surface vessel. The extraction pump must be adjusted to keep the Brix of the extracted liquor correct, and the feed must be regulated to keep the level constant in the sump.

Lillies may operate in single or multiple effect (page 97). If in single or double effect there will generally be a vacuum in the body of the vessel, and the feed can be sucked in. If the evaporator has three or more effects, the first, and perhaps other, effects may have a pressure inside them and it will be necessary to pump in the feed.

The arrangement of the heating tubes in the Lillie is peculiar. A short distance from one end of the vessel is a single tube plate which divides the apparatus into two unequal parts. The small part acts as a steam chest for distributing the steam into the heating tubes and to which the steam supply is connected. The other part is the evaporating space and is connected to the condenser and vacuum pump. Expanded into the tube plate are a number of tubes, about 4″ in diameter and about 5 feet long. These tubes are closed at one end. Their open ends open into the steam chest. They are not quite horizontal ; the closed ends which project into the evaporating space being a little higher than the open ends. Steam enters the tubes from the steam chest and parts with its heat to the liquor through the tube walls. The resulting condensed water runs back along the bottom of the tubes into the steam chest which is provided at its bottom with an outlet through a trap. This arrangement of blind alley tubes is clearly very apt to encourage the collection in the blind end of the tubes of any air that may be in the steam. Each tube is provided with a nipple in the top of the blind end. The nipples have very small holes through them. As there is always a greater pressure inside the tube than in the evaporating space, there will be a constant escape through the nipples which carries away any air that may collect.

The Lillie was the first really satisfactory film evaporator, and its adoption by us for evaporating goldie, 40 years ago, was a process improvement of outstanding importance.

THE LILLIE FILM EVAPORATOR.

Fig. 73 is a cross section of a Lillie film evaporator. The evaporator consists of a horizontal cylindrical shell divided into two parts of a tube plate. Steam is admitted on the left and enters the tubes which are
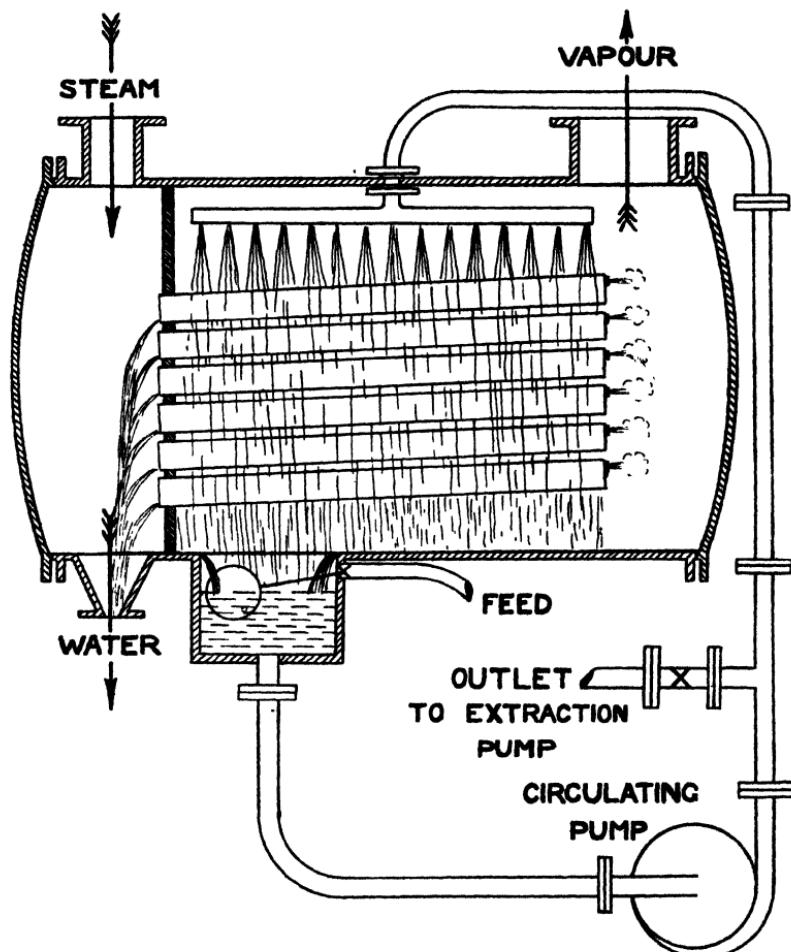
Fig. 73
The Lillie Film Evaporator.

arranged slightly uphill. The water condensed from the steam runs back along the bottom of the tubes and out at the bottom of the steam space through a trap. The tubes are closed at their high ends which extend into the evaporating space of the vessel. The liquor being thickened up is pumped by a circulating pump from the sump in the bottom of the vessel through a spray pipe in the top. It runs over the tubes in a thin film back into the sump. The evaporating space is connected through the vapour outlet to a condenser and vacuum pump. Nipples, pierced by small holes, are fitted to the top end of the tubes to allow any air or gas to escape. The thick liquor is drawn out of the system by an extraction pump which must be adjusted to withdraw the exactly right quantity to keep the Brix at the desired figure. The sump is either provided with a gauge glass to enable the vessel to be kept correctly full or the feed may be controlled by a ball valve in the sump. The Lillie was the first really successful film evaporator.

THE KESTNER CLIMBING FILM EVAPORATOR.

The Kestner evaporator works quite differently from the Lillie. The Kestner consists of a long, slender, vertical, cylindrical body, with a tube plate top and bottom. Steam is fed into the vessel between the tube plates, so that the tubes are surrounded by steam. The liquor to be evaporated is led into the space below the bottom tube plate so that it can enter and stand a little way up the open bottom ends of the tubes. The space above the top tube plate is enlarged and forms the vapour space where the vapour separates from the liquor being evaporated. Round the top of the top tube plate a kind of gutter is formed in which the thick liquor is collected. The vapour outlet of the separator is placed in such a way as to give the vapour a swirling motion so as to assist in separating the vapour from the liquor. The vapour outlet is led to a condenser and vacuum pump. The liquor at the start should be just a few inches up the tubes. When steam is put into the space surrounding the tubes the liquor will start boiling in the bottom of the tubes. Now the action of this evaporator may sound far-fetched, but the action can be watched in the glass Kestner that we have in the Laboratory. A bubble of steam forms in the bottom of the tube and this gets larger until it touches the sides of the tube, when greatly increased evaporation takes place because the walls of the bubble are so thin. The bubble therefore rapidly increases in size, and the film-like walls of the bubble evaporate rapidly, and, owing to the great generation of steam, the bubble goes on expanding and travelling more rapidly
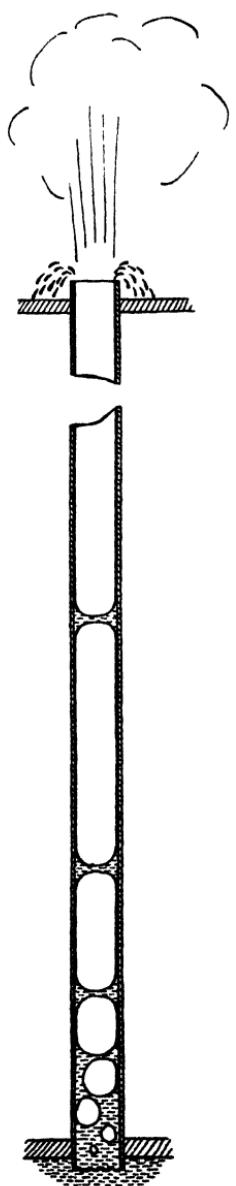
The Fig. 74, alongside, shows a single tube of a Kestner climbing film evaporator. The tube is about 3 or 4 inches in diameter and some 20 to 30 feet long. The tubes are expanded into the tube plates top and bottom. Steam is admitted to the space between the plates and surrounds the tubes. The liquor to be evaporated is fed into the space below the bottom tube plate and stands a few inches or at most a foot or two up the tubes. The space above the top tube plate is enlarged and forms the separator where the vapour leaves by a passage which gives it a swirl so as to leave the liquor behind. The liquor runs across the tube plate and down the side of the separator into a gutter from which it can be drawn by a pipe which leads to an extraction pump or to an atmospheric pipe. When boiling starts, a bubble of steam forms in the tube, and this bubble rapidly enlarges due to the evaporation of the liquid forming the bubble walls, and the bubble is soon rushing up the tube with its walls becoming a thinner and thinner film until the bubble breaks and the rush of steam draws the thin film of liquor up to the separator. Where a great amount of evaporation has not got to be done, the required Brix can be obtained in one pass up the tubes. Clearly, the whole time which any one bit of liquor spends in the heat is very small ; a matter of a few minutes at most.

Fig 74
Kestner Evaporator Tube.

up the tube. The bubble gets longer and goes faster till its top breaks and the rush of steam up the tube drags the film of liquor up the sides of the tube. In the separator, the vapour goes out to the condenser while the liquor runs down the separator walls or across the top of the tube plate into the gutter that is formed round the tube plate. A pipe leads out of this gutter either to an extraction pump or by means of an atmospheric pipe and sealing tank to an outlet.

In the goldie Kestner, at Plaistow Wharf, the evaporation would not be complete with one pass through the tube, so another similar vessel is provided and the vapour and syrup pass from the separator, which in this case is only a transfer chamber into a similar chamber on the top of the other vessel. The steam and syrup then rush down these tubes just as they rushed up the first lot. The vapour separator is at the bottom of the second vessel.

TABLE XI. (See Fig. 93, page 381)

SELF–EVAPORATION OF SUGAR SOLUTIONS.

Brix of Hot Liquor. (Between 75°C and 100°C)	Brix of Cooled Liquor after a Temperature Drop of °C.			
	5	10	15	20
60	60 ·4	60 ·8	61 ·3	61 ·7
62	62 ·4	62 ·8	63 ·3	63 ·7
64	64 ·4	64 ·8	65 ·3	65 ·7
66	66 ·4	66 ·8	67 ·3	67 ·7
68	68 ·4	68 ·8	69 ·3	69 ·7
70	70 ·5	70 ·8	71 ·3	71 ·8

SELF–EVAPORATION.

When the pressure on a liquid is reduced so that the boiling point of the liquid, due to its reduced pressure, is lower than its temperature, it will boil in a quick flash and give up its excess heat to the evaporated vapour until it has cooled itself down to the boiling point at the reduced pressure. This is clearly a way of cooling down a hot liquid, and, as it results in a little evaporation, it is very useful in certain cases, such, for example, as our brown liquor which is made hot in order to filter easily but should be cooled as soon as possible so as not to lie in heat in the tanks before the chars.

The vessel in which we carry out this self-evaporation we call the "cooler-evaporator," and it is described in Chapter 12, page 253.

MULTIPLE EFFECT EVAPORATION.

This has been discussed in Chapter 5, but there is no harm in a little repetition, especially about a subject which seems apt to be misconceived. Evaporation by steam necessitates a transfer of a large amount of heat, called latent heat, from the heating substance to the substance being evaporated. As latent heat leaves the heating steam the steam condenses into water, and as latent heat is taken up by the substance being evaporated, water is changed into steam. This transfer of latent heat cannot take place unless there is a temperature difference, accompanied by a pressure difference, across the heating surface. So long as we can arrange for a sufficient temperature drop we can go on transferring our latent heat. Each extra time we use the latent heat we get a free evaporation because we only had to burn our coal once to put the original latent heat into the boiler steam. This sounds just lovely, but for sugar liquors the high temperatures that have to be used rather take the gilt off the gingerbread. Another difficulty with sugar liquors is the boiling point elevation which is just so much dead loss of temperature difference. None of these complications occur with water. It does not mind up to about red heat how hot it is heated, and it has no B.P.E.

MULTIPLE EFFECT WATER STILL.

At Plaistow Wharf, we generate heat in a portable form in our high pressure boilers at 650 pounds per square inch. This steam is all reduced to 70 lb. for use in the process. A large amount is reduced in pressure by passing through the turbine and making electricity. The remainder must be reduced to 70lb. by some other means. The reduction in pressure down to 70lb. can be accompanied by the production of distilled water for boiler feed. Most of our steam returns, after parting with its heat to the process, as trap water—theoretically pure condensed distilled water. But there is a risk of contamination with sugar. At the very high temperatures in our 650 lb. boilers, sugar is decomposed into acids which can corrode the steel of the boiler. We therefore reduce our surplus high press steam through a multiple effect evaporator which evaporates the boiler feed water so that we have pure distilled water with no risk of contamination for our high press feed. As there is never more than half our steam going through this evaporator, and sometimes much less, we had to make it in four effects in order that it should always, even when dirty, be able to provide sufficient feed water at all times. (We call this plant the STILL because it is essentially a plant distilling water. We are only concerned with its output as gathered from the calandrias as distilled or condensed water, not with the " thickened up " water which we have to blow down from time to time. In a liquor evaporator we are only

interested in the condensed water as a useful bye-product, our principal concern is the liquor which we have been evaporating. We therefore call such a plant an Evaporator.)

The four vessels are identical except for the strength of their shells. They consist of calandria vessels about 11 feet in diameter, and each calandria has some 1,800 tubes $1\frac{1}{2}''$ in diameter and 9 feet long. High press steam from the 250 lb. main is admitted to the calandria of the first vessel, and the body of the last vessel is connected to the 70 lb. process main. As the calandrias are all identical, the temperature drops will space themselves out equally provided that all the heating surfaces are equally clean. If the plant is working fully, the pressure on the first calandria will be 250 lb. at a temperature of 208°C. The temperature of 70 lb. steam is 158°C., so that the total drop is 50°, or a drop of $12\frac{1}{2}°$ over each vessel. The temperature in the first body and second calandria will be $195\frac{1}{2}°$, corresponding to a pressure of 190 lb. In the second body and third calandria, the temperature will be 183° with a pressure of 140 lb. In the third body and fourth calandria, the temperature will be $170\frac{1}{2}°$, and the pressure 100 lb. It will be noticed that while the temperature drop is constant the pressure drop becomes less and less, namely, 60, 50, 40 and 30 lb. The steam from one body is fed into the calandria of the next, and as there is a temperature drop across each heating surface the heat from the steam in the calandria must be transferred to the water in the tubes, and this water will boil. We therefore get four lots of steam condensing in the four calandrias into four lots of distilled water, and boiling off four lots of steam, the last of which feeds into the 70 lb. main. The four lots of water will not be quite equal but will gradually get less because at each evaporation at a lower pressure, a little more latent heat is needed and, as the condensed water leaves each calandria at the temperature of boiling at the pressure it has on it, there will be a drain of heat at each step for this reason. Working things out from the steam table, we find that if the feed water to the Still is at 80°C., and if we put the distilled water out through heat exchangers at 105°C., then one pound of 250 lb. steam will make 3.78 lb. of distilled water and ·86 lb. of 70 lb. steam.

If the demand for 70 lb. steam becomes less, the automatic valve controlling the 250 lb. steam inlet to the Still will close a bit. Let us assume that it has closed sufficiently to reduce the pressure in the first calandria to 160 lb., which means a temperature of 188°C. The temperature-drops over each vessel will now have to be $7\frac{1}{2}$°C., so that the intermediate pressures will be 134, 110 and 88 lb.—pressure drops of 26, 24, 22 and 18 lb.

This automatic smoothing out of the temperature drop may seem too good to be true, but a little consideration will show that it must

be so.   Suppose that the pressure on one of the intermediate vessels goes up.   At once the pressure drop across the calandria that this steam is feeding increases so that a larger evaporation will take place in the next vessel.   This vessel will rise in pressure which will reduce the temperature drop.   Also, across the calandria which is producing the steam that we have considered to be rising in pressure, the temperature drop will have become less, so that there will be a reduction in the evaporation of this steam.   There are, therefore, always two things both tending to ensure steady even evaporation in all the effects.

MULTIPLE EFFECT SUGAR LIQUOR EVAPORATION.

The first, and it may be said to be really a " burning," question that must be settled, is how hot can we allow a sugar liquor to get during boiling.   If we are using a film evaporator, a much higher temperature can be permitted than with a calandria plant because the liquor will only be hot for a much shorter time.   At low Brix, much less damage is done than at heavy weights.   We can, therefore, arrange our evaporator to take the light liquor into the first and hot effects first, while the last, cool effect can evaporate the heavy liquor. Let us see what the Brix and temperatures will be in actual practice under certain conditions.

We will suppose that we have a light liquor of 10° Bx which we wish to thicken up to 70°Bx.   We will suppose that we have a steam supply at 15 lb. pressure and that we have confidence that we can provide a condenser and vacuum pump which will give us 27″ vacuum on our last effect.   Experience has told us that an economical plant for the kind of work we are contemplating must have a temperature drop of at least 15° across each heating surface.   (This figure of 15° is simply taken for this example and is not a rule we adhere to.   Each problem has to be considered in the light of its own particular conditions.)   For working out the temperatures and Brixes, it does not matter whether the evaporator is film or calandria. Our Steam supply is 15 lb. at a temperature of 121°C., and a vacuum of 27″ corresponds to a temperature of 46°C. with water.   We have then got a temperature drop of 75°, less the various B.P.E.'s in each effect.   Now the B.P.E. at 70° Brix is found, on page 204, to be 4° to 5°, so that our temperature drop cannot possibly be more than a useful 71°.   We therefore cannot work with five bodies, called quintuple effect, because that would need $15 \times 5 = 75$°C.   Quadruple effect will probably be all right.   Let us see.   We want to know the B.P.E. in each effect.   We must, therefore, first find the Brix in each effect. Things must be arranged so that we get about the same amount of evaporation in each vessel.   (We shall assume that this can be ensured by making each vessel with the same heating surface and giving it the same temperature drop.   This will not be quite

accurate, as a heavy liquor evaporates slower for the same surface and drop of temperature than does a light liquor. For the purpose of this explanation what we are doing is quite near enough.)   We end up with 70° Brix liquor, that is a liquor with 70 of solids and 30 of water.   We start with light liquor of 10° Brix, that is, 1 of solids to 9 of water.   So that our 70 out must have come in with $9 \times 70 = 630$ of water.   We therefore have to evaporate 600 of water per 70 of solids, or 150 in each effect.   Our liquor will pass through the following stages in the four effects.   The B.P.E. figures are only estimates except at the entering value and in the fourth body.   But the error can only be very small as reference to Table VIII., page 204 will show.

		Entering	First Body.	Second Body.	Third Body.	Fourth Body.
Solids	...	70	70	70	70	70
Water	...	630	480	330	180	30
Total	...	700	550	400	250	100
Brix	...	10	12 ·75	17 ·5	28	70
B.P.E.	...	(·1)	·1	·3	1 ·5	3 ·9

The total of the B.P.E.'s is 4.8, which must be deducted from the gross overall heat drop to get the net total heat drop.   (The reason for deducting the B.P.E.'s is that the vapour, which has to heat the liquor in the next effect up to its elevated boiling point, is not at the elevated boiling point, and the effective temperature drop is between unelevated vapour temperature on one side and elevated boiling liquid on the other.   The gross temperature drop is 75°C, so that the net available drop, after allowing for the B.P.E.'s, is 70 ·2°C. This allows us a drop of temperature across each calandria of nearly 18°C. Let us see what the various boiling liquor temperatures will be.   Steam enters the first calandria at 126°C so that, after a temperature drop of 18°C, the liquor in the first vessel will boil at 108°C. This liquor has a B.P.E. of ·1°C, so that vapour will come off this body at 107 ·9°C at a pressure of 4 ·7 lb. per sq. in.   The second body will boil at 107 ·9 —18 = 89 ·9°C.   As the B.P.E. in this vessel is ·3°C, the vapour will come off at 89 ·6°C with a pressure of 9 · 6″ vacuum. The third body will boil at 89 ·6 —18 = 71 ·6°C, the B.P.E. is ·5°C, so that the vapour will come of at 71 ·1°C, corresponding to a pressure of 20 ·2ᵃ vacuum.   The last body is connected to the condenser, and the liquor in the body must boil at 71 ·1 —18 = 53 ·1°C.   The B.P.E. in the last vessel is 3 ·9°C, so that the vacuum to be maintained by the condenser must be equivalent to a temperature of 53 ·1 —3 ·9 = 49 ·2°C.   This means a vacuum of barely 26½″.

We have now found out that our evaporator will have a tem-

perature of 108°C. in the first effect, where the Brix of the liquor will be 12·75°, and a temperature of 89·9°C, at a Brix of 17·5°, in the second effect. We are now in a position to decide whether the design of evaporator which we have in mind is suitable for the liquor we have to deal with.

This long working out of the state of affairs in a multiple effect sugar liquor evaporator may, perhaps, have been rather wearisome, but it is hoped that it will have given the reader a real understanding of the problem and dispelled some of the misconceptions which exist.

CHAPTER 12.   FILTRATION.

> . . .   *like a fountain troubled,*
> *Muddy, ill-seeming, thick,*   . . .
>
> SHAKESPEARE—Taming of the Shrew—1593.

Meaning of Filtration—Sugar Impurities—Coarse Filtration—Straining—Filter Aids — Types of Filter — Leaf Filters — Working of Leaf Filters—Building up the Cake—Smearing—Sweetening Off—Plate and Frame Filter Presses—Cross Washing—Mud or " Depot " Pressing—Liquor Conditions for Good Pressing — Cooler Evaporator — Carbonatation — Saturation — Kieselguhr and Plaster.

This Chapter deals with Filtration in a very brief way.   This Book is not a description of Sugar Refining ; it is only intended as an aid to the understanding of sugar refining, and a detailed description of each process is not one of its objects.

MEANING OF FILTRATION.

By Filtration we mean the removal of undissolved solids from a Liquid.   The word Filter comes from the Latin word filtrum, meaning felt.   We generally call filtration " Pressing " because the filter plant used is called a filter press.   Many sugar refiners use the words filtration and filter for the char process.   We call treatment by char " Charring," and the vessels in which it is done " char cisterns."

SUGAR IMPURITIES.

The impurities in raw sugar consist of two types : undissolved impurities, like insects, stones, sand, clay, bacteria, pieces of cane fibre or beet pulp, etc., and dissolved impurities like metallic salts and colouring matters.   In addition there are intermediate substances such as gums and waxes which, although dissolved, can be so treated as to flocculate or coagulate into soft lumps which can be removed by filtration.

It has been found desirable to divide the filtration of sugar liquor into two parts—first a very rough crude straining—second, a very fine filtration.   The reason for doing the preliminary rough straining is that unless this is done much trouble is caused in the fine filtering plant by the blocking up of passages, valves, etc., by rough stuff which is easily removed by the coarse filtration.

COARSE FILTRATION—STRAINING.

The first coarse filtration of our raw or brown liquor is a simple straining through a metal sheet full of small holes.   This takes out string, bag fluff, stones, coarse grains of sand, pieces of cane, bits of wood, large insects, etc.   In order to keep the strainer plate from getting clogged the plate is continually swept by wire brushes attached to a travelling chain.   We used to think it necessary to blow air through the holes as well as brushing them, but we have found that the air did little good to the strainer and some harm to the liquor (see pages 15 & 182).

FILTER AIDS.

The substances removed by the fine filtration are clay particles, bacteria, and other very fine things.   These, if collected together, would appear to be a sort of slime.   Such a slime would very soon choke up the cloth used to filter the liquid, so what is called a " filter aid " is used.   A filtering material must be a fine network or felt which will allow the liquid to pass freely but which will trap the solid particles.   In the laboratory a very thin blotting paper is used for filtration.   The fibres of the paper allow the liquid to pass through but entangle the solids.   As the solids build up on the surface of the paper they gradually block up the spaces between the fibres until the paper becomes choked and the liquid can only pass through with greater and greater difficulty.   In the laboratory it is quite easy to use a comparatively large filter paper for a small amount of liquid. In the factory blotting-paper filtration would be quite out of the question because it is too slow and needs such a large amount of paper surface for very little liquid.   In order to keep the size of the filter down within reasonable limits it is necessary to pump the liquid through the filter under pressure and blotting paper is so weak that it would be burst through.   A strong cotton cloth is used.   If a cloth alone were used it would be necessary to use an exceedingly thick expensive cloth if the crevices between the cotton fibres were to be sufficiently small to catch all the tiny particles that we want to trap.   This would be too costly.   Also, in a very few minutes the cloth would become choked with slime and would soon pass little or no liquid.   So we use a filter aid.

A filter aid is a solid substance which will not dissolve in the liquid being filtered and which is composed of particles sufficiently big to be easily caught by the filter cloth and which will make a felt on the top of the cloth which will pass the liquid but whose crevices are small enough to catch all the solid particles in the liquid.   If the filter aid is mixed with the liquid that is to be filtered the filter aid is continually being caught and is providing a continuous new filtering surface so that the filter surface never gets slimed up.   In this way a filter can be used for an hour or more until the filter aid

has built up a " cake " of an inch or more in thickness, and yet this cake will readily pass the liquid because the slimy fine solids have never had the chance of completely blocking up any layer of it.

By using a filter aid it is possible to use a cheaper and thinner filter cloth because the cloth has only to be thick enough to trap the comparatively large filter aid particles. The cloth need not be fine enough to do any real filtration, that is done by the felt built up by the filter aid.

Probably the best filter aid that we know of is plaster—calcium sulphate. When plaster is allowed to form crystals in water under certain special conditions by agitating the plaster in a particular manner at a particular temperature, it can be made to form long thin needles which make a perfect felt which offers a very free passage to the liquid but easily catches the solids. The disadvantage of plaster as a filter aid is that it is slightly soluble in water or sugar liquor and therefore adds to the ash of the liquor. When the liquor is concentrated in vacuum pans or evaporators, the plaster is thrown out and forms a very hard scale on the heating surface.

Another excellent filter aid is paper pulp. This has the disadvantage that it is too expensive to throw away and is difficult to clean for use again. Another disadvantage is that a little filter aid often accidentally passes through the filters, especially when they are first started and are " brightening up " and any paper pulp that may have passed through may collect as a sort of sheet of paper in other parts of the process, on the surface of the char for example, and cause trouble. We have had no success with paper pulp but there is at least one large refinery in U.S.A. using it successfully.

Kieselguhr—also called diatomite or infusorial earth—is the recognised standard filter aid. It is a natural mineral found in various parts of the world. It consists of the skeletons of microscopical water creatures and forms an excellent filtering felt.

Freshly precipitated chalk is a fair filter aid and when produced by the process called " carbonatation " is attended by such other advantages that we use it in all our refineries for raw liquor filtration. Carbonatation has, however, a serious disadvantage in that it causes a destruction of invert sugar, which accounts for the fact that it is not used at all by refiners in U.S.A. In Europe, however, where the white sugar quality standard is higher than it is in America, the improved quality of carbonated liquor outweighs this invert loss.

TYPES OF FILTER.

Apart from bag filters, which disappeared from our refineries 40 years ago, there are only two types of pressure filter in use in sugar refineries, the Leaf Filter and Plate Filter. The plate filter

was a great improvement on the bag filter, but for large-scale work has now been ousted by the leaf filter. The plate filter press is still an essential part of our plant as will be explained further on. The outstanding advantage of the leaf filter is that the proportion of its time when it has to be out of filtering service for cleaning is small. One of its disadvantages is that the cake built up on the cloth is much wetter than the cake built up in a plate press. A plate press can only be actively filtering for about half its time, whereas a leaf filter can be in active filtering service for at least four-fifths of its time. Further, a leaf filter needs only one man to clean it, while a plate filter needs two men. The largest practical plate filter is only about half the size of a moderately big leaf press. But for very difficult high-grade filtration there is no doubt that the best results are obtained from a plate press. The cloth on a plate press is more expensive than the cloth which can be used on a leaf press and the cloth gets much harder treatment on a plate press.

<div align="center">LEAF FILTERS.</div>

There are a number of different kinds of leaf filter. The principal makes are Kelly, Sweetland, Vallez and Suchar-Auto. The Kelly was the first, but it was the Sweetland that swept the plate presses out of the world's sugar refineries fifteen or twenty years ago. The Kelly and the Sweetland have fixed leaves ; the Vallez and the Suchar have rotating leaves.

A leaf filter press consists of a strong cylindrical body three to five feet in diameter and ten to fifteen feet long. The liquor to be filtered is pumped into the body, which must be strong enough to withstand a pressure of about 50 lb. square inch. Inside the body are arranged the leaves, which in the Sweetland are round and in the Suchar are oval. The leaves are spaced from three to six inches apart. There are 72 leaves in our Sweetland presses and 56 in our Suchar presses. The leaf in the Suchar is one and three-quarter times the area of a Sweetland leaf, so that a Suchar press is equivalent to one and one-third Sweetlands. The leaves are made of wire mesh made with thick wire woven closely together. The edge of the wire disc is fitted with a U-shaped channel all round it. This makes a smooth edge to the disc and acts as a liquor passage. The leaf is fastened into the press by means of one or two tubular lugs which serve the double purpose of securing the leaf and acting as liquor passages. In the Sweetland press the leaves are fixed to the body of the press by one tubular fastening which suspends the leaf from the top of the press body. In the Suchar press each leaf is secured to a rotating frame by two lugs one of which acts as a liquor outlet.

The filter cloth consists of two closely-woven cotton discs placed on either side of a wire mesh leaf and tightly sewn together at their

edges so that the leaf is completely enclosed in a cotton case.

Each leaf has its own separate outlet from the press. Each outlet is fitted with a sight glass and a stopcock so that if a cloth should tear or puncture and allow cloudy liquor to flow, the faulty leaf can be identified and shut off without shutting down the press.

THE WORKING OF A LEAF FILTER.

The unfiltered liquor is pumped into the body of the press. The only way it can get out is by passing through the cloth and then along the interstices between the wire mesh and the cloth into the channel round the edge and so into the outlet lug.

The filter aid deposits on the cloth and after a few minutes builds up a sufficient " cake " to act as a filtering medium, and the liquor that entered muddy comes out clear and brilliant. The first lot of liquor is always cloudy until a sufficient felt of filter aid has built up on the cloth to catch all the solid particles.

As filtration proceeds the cake gets thicker and thicker and naturally a gradually increasing pressure is needed to force the liquor through the thicker cake. As a cake is being built up on each side of each leaf the two cakes on adjacent leaves gradually get nearer one another. Just before they touch, when the press would contain one solid cake, the liquor is shut off the press. This stopping point is found by experience. If the press is kept on until adjacent cakes meet it is much more difficult to remove the cakes than if they are left thinner so that they do not touch each other. It is seldom that filtration is so good that the filling up of the press with cake determines the stopping point. Usually the flow of liquor becomes small and the filter is shut down before a full cake has been formed.

After the liquor has been shut off an exhausted press, a valve in the bottom of the body is opened and the liquor in the body is run off. The cake is then sluiced off the leaves. Running along one side at the top of the press body is the sluicing pipe. This pipe has nozzles fitted in it between each pair of leaves. The pipe can be turned to and fro so that the jets from the nozzles sweep across the entire surface of the leaves. The gear by which the pipe is rocked to and fro also causes the pipe to travel a short distance lengthwise out and back by an amount equal to the space between the leaves. By this means the entire space between the leaves is swept by high pressure water jets which quickly wash the whole of the cake out of the press. The operation of sluicing off the cake takes from five to eight minutes. After the sluicings have drained out of the press body the press is ready to be put on to the filtration of liquor again.

A Sweetland press will usually run on ordinary Cuban liquor for rather more than an hour. It then takes about twelve minutes

to drain and sluice it ready for another run.

BUILDING UP THE CAKE.

After the press is first put on and the body filled with liquor, it is important that the liquor should be run very slowly into the press. The pump which pumps the liquor to the presses delivers liquor at a pressure of about 50 lb. square inch. This pressure is needed to drive the liquor through a " full cake " of filter aid in a press that has been on for some time. If the cake is an inch thick this means that each tenth of an inch of cake offers a resistance which requires 5 lb. pressure to overcome it. If at the start of the run of a press, when there is only, say, a tenth of an inch of cake, the liquor valve is opened up so as to allow a pressure of 30 or 40 lb. into the press the cake will be compressed so hard that it will pack tight and allow only very little liquor to pass. Before the cake has become a quarter of an inch thick the flow may be so small that it is not worth while running the press any more. The press should be started very gradually and from the time the press body is full the pressure should only be allowed to rise slowly and smoothly at the rate of about 1 lb. square inch per minute. The cake will then never get unduly compressed but will remain porous. This is one of the great secrets of good pressing.

SMEARING.

The coating or smearing of the cloth with filter aid at the beginning of the run of a press is very important. If much pressure is used the filter aid is forced into the cloth instead of lying like a felt layer on the top of the cloth. This will clog the pores of the cloth right from the start. Smearing the cloth should be done as carefully as possible with the least possible pressure.

Sometimes it is desirable to smear the cloth with a better filter aid than that used during the run of the press. We often use Kieselguhr to smear our presses on carbonatation liquor. This greatly shortens the time needed for the press to " brighten up."

SWEETENING OFF.

The cake that is sluiced off the leaves consists of about quarter solids and three-quarters liquor. The spent filter aid must be washed free of sugar before it is disposed of. We use about ·4% of lime on melt. This becomes over 1% after carbonatation when it has been converted into chalk and has picked up various impurities by filtration. The sluiced-off cake will therefore contain about 3% of liquor at, say, 68° Brix, which means 2% of sugar on our melt. This will amount to, say, 160 tons a week, worth about £2,200

It is possible to wash the sugar out of a cake in a leaf filter by

just following up the liquor with water.   This is very slow and makes a lot of sweet water and light liquor.   In the case of a Sweetland press the cake washes off patchily because the cake is always thinner at the top than at the bottom of the leaves.   On the Suchar it is possible to sweeten off the cake completely and evenly because, owing to the rotation of the leaves, the cake is of an even thickness all over.   One of the principal reasons for installing Suchar presses at Plaistow was because it was possible to sweeten them off.

The procedure of sweetening off a Suchar is as follows.   When the press has finished its filtering run the liquor is turned off and compressed air is turned on.   This air is simply to hold the cake on to the leaves while the liquor is being drained from the body of the press.   As soon as the press is empty the drain valve is shut, the wash water is turned on and the air turned off.   It is a somewhat tricky business and takes a long time, and it keeps a big expensive piece of plant out of commission.   We now never try to sweeten off the cake in a Suchar or other leaf press, but do all our cake washing in plate and frame presses.

PLATE AND FRAME FILTER PRESSES.

Plate and frame presses were ousted from liquor filtration about twenty years ago by leaf filters.   But plate and frame presses had themselves some twenty years earlier displaced bag filters.   For really high-class difficult filtration the plate and frame press is still supreme.   Its disadvantages are that its capacity is small, that it has to be out of action for about half the time for cleaning, that it requires more labour, that it needs an expensive cloth and it is prone to be leaky.   The Plate and Frame filter press consists of a pack of plates and frames squeezed tight together.   Plates and frames are arranged alternately.   Each plate is made of cast iron about an inch and a half thick.   The faces of the plates are ribbed or corrugated except for about an inch all round the edge where they are planed smooth.   The frames are made of cast iron and in our presses are of about the same thickness as the plates and are just like empty picture frames.   The frames can be made of any thickness to suit the particular filtering operation.   When the plates and frames are packed together they form a series of shallow chambers.   Before the plates and frames are packed together a filter cloth is hung over each plate.   This cloth is of a sufficient size to cover both sides of the plate completely, so that the shallow chambers formed by the plates and frames will have walls made of filter cloth.

The liquid to be filtered is pumped into these chambers through passages in the frames.   It passes through the cloth which is supported by the ridges on the plates.   The furrows between the ridges act as channels to lead the filtered liquor to the outlet passages

in the plate. The whole pack of plates and frames, which may
number 50 of each, is pressed together by a powerful screw or
hydraulic jack. The edges of the frames squeeze the cloth against
the planed rim round the edges of the plates, forming tight joints
for each filtering chamber.

The liquor passages in plates and frames lead into the main
liquor inlets and outlets. These are formed in lugs or ears on each
corner of the plates and frames. Through the middle of each lug
is a large round hole. When the plates and frames are squeezed
together these holes become pipes the full length of the plates and
frames. The joints between the lugs are made liquid tight by means
of rubber gaskets.

The filtered liquor after passing through the cloth finds its way
to the outlet by the grooves and passages in the plate. The filter
aid and the filtered out impurities build up a cake on the cloth walls
of the chamber formed by the frames. The press can be run until
each frame contains a solid cake with no room for any more. The
cake can then be washed free from sweet quickly and economically.
This washing is carried out by means of an arrangement of wash-
water passages in the plates, which will now be described.

This description is rather involved and the reader should go
and look at the passages in a plate press in order to understand the
arrangement.

Each plate and each frame has a lug at each corner. Through
each lug is a hole. When the plates and frames are jacked tight
together these lug holes form four pipes along the length of the press.
Each frame has its liquor passage leading into the hole in the left-
hand bottom corner, so that the left-hand bottom lugs form the
liquor inlet to the frames only. None of the plates have any
connection to the bottom left-hand lugs.

The arrangement of the passages in the plates is not so simple.
There are two kinds of plate which are arranged alternately. We
will call them the odd and the even plates. The odd plates have
their liquor passages leading into the holes in the right-hand bottom
lugs. The even plates each have two sets of passages which lead
into the left-hand top and right-hand top lugs. The reason for this
will be clear in a minute.

The four corners of the press have the following pipe connec-
tions. Attached to the bottom left-hand lugs which lead to the
frames is a branch pipe with a valve on each of the two branches.
One branch comes from the liquor pump and the other is connected
to the wash-water supply. The top left-hand corner, which is
connected to the even plates, is connected through a valve to the

wash-water supply. The top right-hand corner, which is connected to the even plates, is connected through a valve to the liquor outlet box. The bottom right-hand corner, which leads from the odd plates only, leads straight into the liquor outlet box without a valve.

When the press is started, the liquor inlet to the bottom left-hand corner is opened with the wash-water valve shut. This allows liquor into all the frames in the press. The wash-water connection to the top left-hand corner is also shut. The valve on the top right-hand corner is opened, which opens the outlet of the even plates— the outlet from the odd plates can never be shut. The liquor enters the chambers formed by the frames. The only way it can get out is through the cloth and along the grooves and through the outlet passages into the right-hand lugs. In the odd plates the outlet is from the bottom right-hand lugs and in the even plates from the top right-hand lugs. When the spaces in the frames are full of cake the liquor is shut off from the left-hand bottom inlet and the wash-water is turned on to this corner. This forces all the liquor out of the inlet passages and fills them with wash-water. The washing of the cake cannot be done properly by following up the liquor with wash-water through the frame inlet because the water would enter one corner of the cake and would have to percolate through the whole cake edgeways. This would take a very long time and would use a very large amount of water thus making a great quantity of light liquor or sweet water.

CROSS WASHING.

After a few minutes, to make sure that the inlet passages are clear of liquor, the wash-water is shut off the bottom left-hand inlet. The top right-hand outlet is shut off thereby preventing liquor from coming out from the even plates. The valve on the top left-hand corner is opened, allowing wash-water into the even plates. This water passes into the grooves in the even plates behind the cloth. It then passes straight through the cake to the grooves in the odd plates and out by the bottom right-hand outlet. By this means any drop of water has only to pass across an inch and a half of cake and the water is evenly distributed over the whole of the side of the cake. The whole of the cake can thus be washed off quickly and economically.

By suitable additional pipe connections it is easy to arrange that cross washing can be done in both directions—that is from the odd to the even plates, as well as from the even to the odd.

MUD OR "DEPOT" PRESSING.

Except for certain special syrups we do all our filtration on leaf filters. It has already been explained that it is difficult to wash

the cake free of sweet in a leaf filter, so that the sweet cakes are sluiced off the leaf filters and washed elsewhere. When the cake is washed out of a leaf filter it comes out as a slurry. This slurry is filtered and washed in plate presses. The most efficient way of washing mud or depot would be to press the slurry into a hard cake, make no attempt to wash it, but drop it from the press and mix it up with water into another slurry and pump it again into a press, and so on several times. But this would take an excessive time and a great deal of plant. When we sluice off the cake in our leaf filters we use " press washings " (whose origin will appear in a minute); these are at about 7° Brix. If five parts of press washings are used for one part of cake, the resulting sweet water mixed with the cake will be about 15° Brix., if the liquor in the cake was at 68° Brix. The calculation is as follows :—

100 parts of cake contain 25 parts of solids and 75 parts of liquor.

75 parts liquor at 68° Brix. contain 51 of sugar and 24 of water.
500 parts washings at 7° Brix. contain 35 of sugar and 465 of water.
        Total   86 sugar   489 water.
                        or 15° Brix.

The " press water " which comes out of the press when the mud or depot is pumped through the presses will be at about 15° Brix. When the press frames are full of cake the cake is cross washed with Char water (see page 275). This comes out of the press at an average of about 7° Brix. and is the " press washings " used for sluicing off the leaf filters. The heavy Brix press water goes to the recovery house for making down raw syrups.

It is important that the least possible water should be used for washing cake, because, apart from the fact that it all has to be evaporated later, the water dissolves impurities from the cake. Every pound of ash introduced into the process has to go out as molasses when it will take with it 4 or 5 lbs. of sugar (see page 286).

LIQUOR CONDITIONS FOR GOOD PRESSING.

The first essential of any sugar liquor is that it should contain as little water as possible, because all the water has got to be evaporated sooner or later. Brown liquor should therefore be pressed at the highest possible Brix. We find that with certain sugars— Beet, West Indian, Cuban, Mauritian and Javan—it is often possible to press, after carbonating, at 70° to 71° Brix. Liquor obtained from Australian and Natal sugars can seldom be filtered at more than 64° Brix. However easy-filtering the liquor, we find that if we get the Brix any higher than about 71°, we get into trouble with the presses which rapidly slow up. It is important that the Brix., temperature and pH of the liquor be kept as constant as possible.

If too high a Brix or too low a temperature or pH occur even for a short time, the filtration slows up and it is difficult to speed it up again even by reducing the Brix drastically. The presses do not get right again until they have been washed off and started afresh.

One of the great advantages of continuous carbonatation is that the Brix, temperature and pH can be kept more constant than with batch or separate tanks. With batch carbonatation each tank is bound to be somewhat different from the previous one, and the change over from tank to tank is seldom managed without a temporary drop in press pressure. If the press pressure drops suddenly, a part of the cake may fall off the leaf. Through the gap thus formed cloudy liquor will pass rapidly through the cloth because the press may be under considerable pressure which will be too much for an uncoated cloth.

The pH affects the pressing considerably. The higher the pH the easier the pressing, but with a high pH carbonatation is incomplete—this is dealt with later on.

We have sometimes pressed at very high temperatures—105° C. or so. In order to keep the liquor for the shortest possible time at the high temperature it is heated in a steam-heated tubular heater between the pump and the presses, and immediately it leaves the presses it is at once cooled by flash, which also raises its Brix.

COOLER EVAPORATOR.

The cooler used for cooling liquor that has been pressed at an abnormally high temperature is a large empty vessel into which the liquor is sprayed. A float valve maintains the liquor level so that the vessel never empties nor does the level rise above the spray. The top of the vessel is connected to a condenser and vacuum pump. A vacuum of about nineteen inches is maintained on the vessel. As soon as the hot liquor enters the vessel through the spray it comes under the reduced pressure and flashes off steam until it has reached the boiling point appropriate for its Brix and the vacuum in the vessel. If the vacuum was twenty inches we see from Table VI on page 92 that the water-boiling point would be 72° C. Table VIII on page 204 tells us that at 69° Brix under this vacuum the B.P.E. will be 4° C. The liquor sprayed in at, say, 96° C. will therefore come out at 76° C. Table XI. on page 236 tells us that the liquor will have increased in Brix by 1·7°.

This hot pressing is quite successful on easy pressing liquors, when only a few presses are needed and the liquor passes through quickly and is not lying long in heat. But with liquor that is pressing badly, which is when we want to press hot most, the long time in the many presses causes deterioration in colour and invert.

We have recently modified one of our cooler evaporators to give us a considerable increase in Brix at no cost in steam—this is dealt with in Chapter 17 page 311.

CARBONATATION.

The simple chemistry of carbonatation has been described already in Chapter 3, page 61. Carbonatation is somewhat of a mystery. It has a really miraculous effect on sugar liquors, an effect which is not only apparent on the brown carbonated liquor but one which persists through generation after generation of refinery syrups. Carbonatation does a number of things. It provides a cheap filter aid for removing the very fine solids. It entangles gums and waxes. It removes a large amount of colour. It removes some ash. But—it causes some destruction of invert sugar. It would be quite impossible for us to maintain our high quality if we did not use carbonatation. Generally speaking, the European refiners use carbonatation, whereas the American refiners do not. Competition in Europe has been largely on quality, while competition across the Atlantic has been largely by price. The quality of European granulated was (in 1938) much higher than American granulated.

	Colour.	Ash.	Invert.
Average of nine well-known American granulated sugars . . .	42	·009	·033
Best of the above nine samples. .	34	·006	·020
T.L. Granulated—Plaistow . .	11	·006	·008
T.L. Granulated—Liverpool . .	11·5	·004	·005

American refiners consider that the destruction of invert sugar which occurs in carbonatation more than offsets the advantages. The actual destruction during six consecutive half-years at Plaistow Wharf is shown in the following figures.

	Before Carbonatation. Invert %.	After Carbonatation. Invert %.
Summer, 1937 . . .	·15	·09
Winter, 1937/38 . . .	·08	·08
Summer, 1938 . . .	·13	·11
Winter, 1938/39 . . .	·10	·08
Summer, 1939 . . .	·13	·09
Winter, 1939/40 . . .	·12	·10

These figures show that the invert loss amounts to from only a few hundreds to about £3,000 maximum per year. We consider that this loss is small compared to the advantages.

SATURATION.

Carbonatation consists of adding lime cream to the liquor and

then gassing out the lime as a precipitate of chalk with carbon dioxide. This gassing out is called " Saturation " because the liquor should be saturated with gas in order to be sure of throwing down all the lime. The tanks in which the gassing is done are called the saturation tanks. The gas is obtained by washing the boiler-flue gases to free them from sulphur, arsenic and other undesirables. The amount of lime used is about 0·4% on melt. We believe that 0·1% is all that is needed for the actual carbonatation and that we have to use the extra 0·3% simply as filter aid, but this is not yet proven. The lime should be added in small quantities, if possible, in order that the pH shall not rise very high. The higher the pH the greater the invert destruction.

The gassing or saturation should theoretically be carried on until all the lime has been thrown down—that is until the pH has been reduced to 7. Only in this way can it be certain that all the lime will have been removed. If the pH is not brought down to 7 the ash in the liquor ought to be increased. But this, strangely, is not the case. At Plaistow, for reasons to be given in a minute, we generally only gas out to 9·0 or 8·5 pH, yet we do not get any appreciable ash increase. The reason for this is that carbonatation brings ash out of the liquor, and the ash that we have added by leaving the gassing incomplete is balanced by the ash that carbonatation has brought out. If the saturation is carried on until the pH is 7 or thereabouts a really material reduction of ash occurs. During the whole of 1939 at Plaistow when we hardly ever gassed to below 8·5 and were generally nearer 9·0 pH the ash after carbonatation was exactly the same as it was in the uncarbonated liquor.

There are several reasons why we do not gas out to 7 pH. First, the chalk thrown down during the last part of gassing is very fine, and difficult to filter—it can hardly be called a filter aid. Second, we like to put our liquor on to the char in a definitely alkaline condition. Third and fourth (these are excuses, not reasons !), the last bit of gassing is very slow and we are generally impatient, and our gas pumps are not (1939) big enough to keep a big melt going when we try to gas right out.

The actual pH at which we aim depends upon the sugar we are melting and on the amount of ash in the melter liquor, and we vary the pH until we find the best conditions.

In order to determine the end point we use test papers which are impregnated with a suitable indicator (see page 64). If we want to alter the pH by much we have to use a different indicator. We frequently use paper soaked in turmeric. Turmeric has a range of 7·8 to 9·2 pH. This means that yellow turmeric paper commences to turn pink with any pH higher than 7·8 and that the reddish-brown

colour produced with a pH of 9·2 gets no darker however much the pH is raised beyond 9·2. A distinct pink means a pH of about 8·2. A definite dirty red means a pH of 8·9 to 9·0. We have pH meters which automatically indicate and record the pH, and we check these readings by means of the universal indicator (see pages 56 & 64).

With the continuous carbonatation plants at Liverpool and Thames a much lower pH can be reached because the chalk is thrown down in bigger crystals and is a better filter aid.

The more nearly gassing can be carried to a pH of 7 the greater is the ash removal and the colour removal. Even gassing to only 9·0 pH causes a considerable colour removal. During the summer of 1939 the average colours before and after carbonatation at Plaistow were 57 and 35 over six months' working.

The temperature at which gassing is done has a considerable effect on the success of the process. The best temperature is about 50° C. This gives good colour and ash removal and destroys very little invert. We do not work at this low temperature because our melters are too small to melt the sugar at such a low temperature, and the heaters in our carbonatation plant are not big enough to heat up to pressing temperature from such a low gassing temperature as 50° C.

A great deal more could be written about carbonatation, but it might be of little use, because our ideas on the subject are constantly changing. Much of what has just been said may seem wrong in a few years' time.

KIESELGUHR AND PLASTER.

The carbonatation precipitate of chalk is a poor filter aid compared with many other things. When a clean press is put on, the liquor runs cloudy for some minutes before a sufficient cake is built up on the cloth to make a good filtering-felt. In order to shorten the time taken for the presses to " brighten up " we often add a smear of kieselguhr (see page 248).

When melting 100% beet sugar, carbonatation is of little use because all beet sugars have already been heavily carbonated in the beet factory. We generally use kieselguhr as the filter aid when melting all beet and dispense with carbonatation altogether.

Plaster, as has already been said, is probably the best filter aid that we know of. There is one process in which we can use it without any harm ; this is in the filtration of Golden syrup after inversion. This syrup is already saturated with calcium sulphate so that no harm can come from the addition of a little more. The calcium sulphate resulting from the neutralising of the sulphuric

acid used for inversion forms in small square crystals and is not a filter aid. We filter this out together with the excess neutralising chalk and any solid impurities with plaster needles that we have added as filter aid. See Chapter 17, page 364.

Filtration is not a satisfactory process. Leaf filters are very poor tools and plate presses are too costly in labour and cloth. A brand new filtering machine is badly wanted.

CHAPTER 13.   CHAR.

Char, . . .
Renewing an appetite long past its crisis—
Refined barley-sugar, in various devices.

BARHAM—Ingoldsby Legends—1840.

Bone Charcoal—" Active " Carbon—" Adsorption "—Treatment of New
Char — Life of Char— Amount of Char Needed — Revivification of Char —
Driers—Scotch Kilns—Buchanan Kilns—Char Burning—Decarbonisation
—Burning Tests—The Char Cisterns—Packing the Cistern—Liquor Sett-
ling—Water Settling — Dry Settling — Liquor Charring — Exhausting the
Char —" Starts " and " Rates "— Sweetening Off — The Lights Battery —
Washing Off — The Water Battery — Starts and Rates in Battery — The
Liquor " Gallery," " Room," or " Pass."

This chapter does not deal at all exhaustively with Char and
its action or treatment.   A whole book could be written about
char.   The points which are treated most fully are certain practical
things like " starts " and " rates," and the working of the " lights
battery " and the " water battery."

BONE CHARCOAL.

Bone Charcoal, or " Char " as we call it, is a sugar-refining
material quite unequalled by anything else.   There are bleaching
processes which remove, often only temporarily, the colour from
sugar solutions.   There are vegetable carbons which remove the
colour entirely.   But there is no other material which removes the
colour and removes quite a lot of the ash as well, which is moderate
in price, which lasts for many years and which stands up to rough
treatment without rapid loss of efficiency.

Char is made by heating bones from which the grease has been
removed, in a closed retort at a cherry red heat until all the volatile
matters have been driven off.   When this process is complete the
hot burnt bones are allowed to cool before they are allowed to come
into contact with the air.   They are then crushed and graded by
sieves into various sizes.   We use char of about twice the size of
granulated sugar.

The structure of the char is one of its most important charac-
teristics.   It consists of a porous framework of calcium phosphate

coated with carbon. This porous structure is like a microscopic petrified sponge. As a result of this sponge-like structure the char has a very large surface. The calcium phosphate forming the structure makes up about 80% of the weight of the char. Mixed up with the phosphate is a quantity—usually about 7%—of calcium carbonate. The amount of carbon is between 10% and 12%. Of this percentage probably only half is pure carbon, the rest being combined with organic substances. The remaining 1% or 2% consists of sand and traces of calcium sulphate and iron oxide.

" ACTIVE " CARBON

The carbon spread over the surface and pores of the char is not like soot, which is also carbon ; it is what is called " active " carbon. That is to say it has the power of removing certain organic matters, notably colouring matters. It is possible to " activate " carbon obtained from certain vegetable charcoals by somewhat elaborate chemical means. This activation consists of dissolving all the non-carbon bodies out of some carbon-containing material such as wood charcoal and leaving behind a sponge-like framework of carbon, which has a large surface.

These activated carbons can be used for decolourising sugar liquors, but they do not possess the ash-removal powers of char ; they are expensive and their decolourising action is poor on liquors which contain much ash. Efforts have been made for many years to use these carbons as substitutes for char, but only limited success has been achieved. The reason for trying to find a substitute for char is that the char plant is large and expensive to build, and a large amount of char has to be held which locks up money.

" ADSORPTION."

One of the important properties of char is its ability to remove metallic salts—that is ash—as well as colouring matters from sugar solutions. This is due to an action called " adsorption." The Latin word " sorbtum " means " sucked in." The Latin word " ad " means " towards " and the Latin word " ab " means " away from." So the word " adsorption " means " sucked in towards," and the word " absorption " means " sucked in away from." " Adsorption " is a somewhat indefinite drawing away of one substance towards another. It is always selective. That is to say no substance that has adsorptive properties will adsorb just anything. Char adsorbs certain metallic salts, principally calcium salts. It does not adsorb sodium salts. It adsorbs certain organic substances, for example the colouring matters in sugar liquors. " Absorption," on the other hand, is not selective. Blotting paper will absorb any liquid offered to it.

When char adsorbs colouring matter it holds on to it much more tightly than it does to the adsorbed ash. While some colour can be washed out of char, most of it can only be removed by drastic chemical means such as burning or treatment with strong alkali. The adsorbed ash can be removed from the char by lowering the Brix of the liquor surrounding the char and can be entirely removed by washing with water.

This difference between the adsorption of the colour and the ash has been accounted for by various tentative theories. It may be that the colour adsorption is something more than ordinary physical adsorption ; it is possibly a chemical action.

Adsorption is purely a surface action. The greater the surface the greater the adsorption. The porous structure of the char accounts for its excellent adsorptive properties.

TREATMENT OF NEW CHAR.

New char contains a number of undesirable things—ammonium compounds and sulphur compounds. Before using new char on sugar liquors it must be washed and burnt. We often give it a good dose of hydrochloric acid as well to get rid of the undesirable matters more quickly. It takes several weeks for new char to get into proper condition.

LIFE OF CHAR.

When liquor is run over char its power of adsorbing colour and ash gradually diminish until after a certain time—from twelve to ninety hours, depending on the quality of the liquor being treated—the char must be revivified in order to restore its properties. This revivification (revivificare —Latin—to make live again) will be described later. Revivification results in the char being made almost as good as it was before. Char is revivified in a refinery about every five or six days. Gradually it is found that revivification is not quite so successful. The char is deteriorating and losing its qualities. This is largely due to its pores getting blocked up, to a great extent due to faulty revivification. The whole action of char depends on its porous structure. If the pores get choked the surface inside the pores is not available for ash adsorption, nor is the carbon in the pores available for colour adsorption. We consider that the useful life of char is about five years. We do not put out any spent char nowadays. We merely replace the dust that we take out, and the amount of dust loss is, conveniently, such that we replace our char every five years. In addition to dust, we remove a small amount of heavy char (that is char which has lost its light porous structure) by means of the Kipp-Kelly separator.

AMOUNT OF CHAR NEEDED.

Most sugar refineries use about 50% to 60% of char on melt. We use between 15% and 25%. There are two reasons why we use so little. First, carbonatation so improves not only our brown liquor, but the subsequent refinery syrups, that we find our char goes much farther. Second, we only char comparatively little of our raw syrups, whereas the American refiners, for example, char all or almost all. The reason for this difference in transatlantic practice is firstly that there is a ready market in U.S.A. for yellow sugars which are the product of charred raw syrup. Secondly, one of the principal reasons for charring raw syrup is to remove ash so as to make less molasses. This is more important in America than in Britain because the relative value of molasses in U.S.A. is lower than in Great Britain. It does not pay us to char raw syrup solely in order to make less molasses unless we can make a very good profit on the resulting yellow sugars. (Molasses is discussed in Chapter 14., page 285.)

REVIVIFICATION OF CHAR.

After the char has been run on liquor until it is exhausted, it is washed to remove the adsorbed ash and then burnt. The running of the liquor over the char is done in large tanks which we call char " cisterns." (Most of the sugar-refining industry call these tanks char " filters.") The char must be taken out of the cistern for revivification and transferred to a kiln for burning. Various methods have been tried in order to do the revivification in the cistern, because a great deal of damage is done to the char in taking it out of the cistern, passing it through the kiln and putting it back into the cistern. It is all this handling that breaks up the grains of char and makes dust.

It is possible to do a kind of revivification with caustic soda. This dissolves most of the organic matter, but does not give so good a result as burning besides using much washing water. The cistern is out of action for longer than the time taken to empty and fill.

We have tried burning the char in the cistern with superheated steam. This was not successful, but it showed sufficient promise to make us believe that this method could burn char satisfactorily when the practical difficulties have been surmounted.

It is doubtful, however, whether cistern revivification can ever be really satisfactory. Char left for several runs untouched would probably pack tight and cause slow running. Channels would almost certainly form. But the handling of char is a bad business and leaves room for much improvement.

The revivifying process consists of passing the char through a

kiln which first dries it, then heats it up to somewhere in the neigh-
bourhood of 400° C. and then cools it, all out of contact with the
air. We are not sure of the exact temperature that the char reaches
inside the kiln retort pipes—it is difficult to measure this temperature
correctly—but experiments with superheated steam in the labora-
tory show that a temperature of 400° C. is sufficient for perfect
burning, and it does not seem to be necessary to keep the char at
this temperature for any length of time. It is sufficient just to
raise it to the critical temperature and then cool it. We control
the temperature of our kilns by means of the temperature in the
retort chambers—that is to say on the fire side of the retort pipes.
Each kiln is fitted with a pyrometer and we work at a temperature
of about 600° C.

DRIERS.

All sorts of driers are fitted to char kilns. Some of them are
simply upward continuations of the retort pipes. Others work by
passing the char over horizontal triangular pipes through which
the flue gases pass after leaving the retort chamber. Others work
by passing hot air—obtained by drawing the air round the char-
cooling pipes—through the wet char. We have one drier which
combines all three of these arrangements and is very satisfactory.

Most of the heat from the coal burnt in a char kiln is used for
drying the char. The char leaves the cisterns with about 20% of
moisture in it. It is then wet and clinging. As soon as the moisture
is reduced to about 12% the char becomes free-running and looks
quite dry. But until it is free from water it cannot be heated up
above 100° C. Here is a statement of the heat needed to raise
100 lb. of wet char, at 80° C., and containing 20% moisture, up to
400° C. The specific heat (see page 87) of char is ·23.

80 lb. char to be heated 320° C. with ·23 specific
    heat   .   .   .   .   5,888 C.H.U.

20 lb. water to be heated from 80° C. to 100° C.
    with specific heat 1·0   .   .   .   .   400 C.H.U.

20 lb. water to be evaporated with latent heat
    of 539   .   .   .   .   10,780 C.H.U.

                                              17,068 C.H.U.

From these figures it will be seen that two-thirds of the heat is used
in driving off the moisture and only one-third for burning the char.
This shows the importance of an efficient drier.

SCOTCH KILNS.

Scotch kilns consist of vertical oval pipes, the oval being about

four times as long as it is wide. These pipes pass from the bottom of the drier, if fitted, through the furnace, or retort chamber, and then extend downwards some eight feet or so as cooling pipes. The coolers end in draw boxes which discharge into the receiving hoppers. The upper part of the pipes, which serve as driers, and the part which pass through the retort chamber are made of cast iron which is resistant to moisture and heat. The lower cooling portion is made of thin sheet steel in order to dissipate the heat more easily. The char needs to be cooled before it is discharged into the air lest the active carbon be burnt off.

The drawing gear consists of a pair of slides about a foot apart placed in boxes at the bottom of the cooler pipes. When the bottom slide goes out the top slide goes in. This traps the char in the cooler and retort pipe, but allows a foot of char to drop into the receiver. The bottom slide is then pushed in and the top slide drawn out which allows all the char in the cooler and retort pipes to drop a foot. The gear which works the slides is provided with a change-speed gear so that the rate of drawing the char through the kiln can be varied.

Scotch kilns are simple and their upkeep cost is fairly low, but they use a good deal of coal and do not burn the char particularly well.

BUCHANAN KILNS.

In the Buchanan kiln each retort pipe is slowly rotated so that each part of the pipe is evenly heated. The drier pipes and the retort pipes are round, about twelve inches in diameter, and down the centre of each is a louvred vent pipe. These vent pipes are about eight inches in diameter so that the char falls through a ring-shaped space about two inches wide. Below the furnace or retort chamber the round pipe branches into a bunch of oval sheet steel cooling pipes, which end in the discharge boxes. These discharge boxes consist of a pair of small fixed hoppers which fill four small rotating measuring boxes. Each revolution of the retort pipe discharges a measured quantity of char. In order to vary the speed of flow of the char through the kiln it is only necessary to alter the speed of rotation of the pipes, which is done by a gear box.

The Buchanan kiln uses considerably less coal than the Scotch kiln. We think it burns the char better. It has a slight decarbonising action (see below, page 264), but the cost of maintenance is high.

CHAR BURNING.

The char kiln is the most inefficient tool we use in sugar refining, and improvement is long overdue. Char is a very bad conductor of heat. The walls of the retort pipe must be heated to a much higher

temperature than is needed for correct burning. If the inner char, furthest from the wall of the retort pipe is heated sufficiently to burn it, the char nearest the pipe wall must have been heated too much. The Buchanan kiln has a great advantage over the Scotch kiln in this respect because the inner vent pipe has louvres over its openings to prevent the char getting into it and these louvres turn the char over as it passes down the pipe and mix the inner cool char with the outer overheated char.

The burning of char is done out of contact with air, except for the air which is carried along with the char. Some air is necessary in order to burn off the adsorbed organic matter, but it must be the least possible quantity lest some of the active carbon be burnt. It is fortunate, but apparently true, that the active carbon is more difficult to burn than the carbon resulting from the carbonisation of the adsorbed organic substances.

The temperature is low and the burning is very quiet and slow. A splitting up or distillation takes place first, leaving carbon behind to be burnt when the char reaches a region of higher temperature lower down the pipe. If the retort is too cool to burn off this carbon it clogs the pores of the char and revivification has not been properly effected. It is therefore necessary to make frequent analyses of the carbon in the char. This carbon which is left in the char due to imperfect burning is not active carbon and is useless for colour adsorption. If the carbon in the char is found to be increasing in spite of an adequate burning temperature it may be necessary to " decarbonise " the char (see below).

The ideal char-burning plant would raise all the char to exactly the right temperature without any variations. Direct heating of the char by contact with a hot gas would do this. Superheated steam has been tried with some promise, but steam is not an ideal medium because all the latent heat in it must be thrown away. The steam cannot be used after it has burnt char because it contains all the products of the burning. Flue gases would be the cheapest of all things, but they contain undesirable impurities such as arsenic and sulphur. Direct contact heating is the obvious method because every particle of char can then be heated to exactly the right temperature without any risk of some being overheated and some being underheated.

Small fragments of the iron scale from the kilns are continually being picked up by the char. Iron is a very undesirable impurity in a sugar liquor, so the char is passed over a magnet after leaving the kilns.

DECARBONISING.

In order to decarbonise char that has accumulated inactive

pore-blocking carbon, all that is necessary is to burn the char in the presence of a little more air than usual. Years ago we used a Weinrich decarboniser, which is just a piece of plant like a coal-heated granulator. More recently we altered some of the Plaistow kilns so as to be able to allow the entry of a little air into the bottom of the retort pipes. In recent years, however, due to improvements in char washing and carbonatation we have not found any increase in the carbon in our char—rather the reverse. We often find old char has lost carbon instead of gaining it.

BURNING TESTS.

In order to find out whether the char is being properly burnt there are certain simple chemical tests. The practical full-sized test of waiting to see what happens when the char is put on liquor is not satisfactory. Bad results may not be due to bad burning. The liquor may be at fault.

Most of the adsorbed organic matter can be dissolved in hot caustic soda. Each kiln is sampled every shift and a weighed amount of char is stewed for a constant time in a certain amount of caustic soda. The soda is then decanted off the char and its colour is measured. Well burnt char should give only a faint yellow tint to the soda.

Char must not be overburnt—that is heated to too high a temperature—as this might cause the active carbon in the char to be burnt. Even if there is no oxygen present to combine with and burn the active carbon, some of the radicles of some of the calcium salts may split up and provide the necessary oxygen. When char is heated to a temperature just above burning heat, the calcium sulphate in the char will split up into calcium sulphide and oxygen by reason of the carbon acting as a " reducing agent." The carbon will " reduce " the sulphate to the simpler sulphide.

$$
\underset{\underset{CaSO_4}{\text{Calcium Sulphate}}}{\text{1 Part}} + \underset{\underset{2C}{\text{Carbon}}}{\text{2 Parts}} = \underset{\underset{CaS}{\text{Calcium Sulphide}}}{\text{1 Part}} + \underset{\underset{2CO_2}{\text{Carbon Dioxide}}}{\text{2 Parts}}
$$
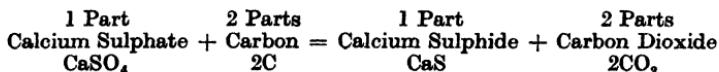
We therefore test all our newly burnt chars for sulphides, by adding lead acetate to the caustic soda that was used for the under-burning test. If sulphide is present a black precipitate of lead sulphide is thrown down.

It frequently happens that chars will test both overburnt and underburnt. This, after all, is only what is to be expected with kilns as they are. The char nearest the retort pipe wall is overburnt and the char furthest from the heat is underburnt.

THE CHAR CISTERNS.

Most of the cisterns that we use for charring liquors and syrups are ten feet in diameter and twenty feet deep. There are seventy-seven such cisterns at Plaistow Wharf. When filled with char and liquor they contain about forty-five tons of char and rather more than 5,000 gallons of liquor. At the bottom of the cistern a perforated false bottom made of cast iron or aluminium is fitted. This false bottom rests on ribs on the inside of the cistern bottom. The outlet pipe comes off the bottom of the cistern below the false bottom. On the false bottom is spread a canvas sheet, which supports the char and keeps it from running out of the cistern and blocking the outlet. This sheet is a favourite breeding place for bacteria. Every time the cistern is emptied the sheet is taken out, washed and then sterilised in an autoclave with 20 lb. steam. Some of our cisterns are lined with tiles to prevent acid syrups from dissolving iron from the cistern walls. We are experimenting with rubber linings, but have only had three years' experience with these and do not yet know their life. At the top of the cistern is the man-hole through which the cistern is filled, also the liquor inlet pipe and the vent pipe. The vent pipe is carried up to the top of the building above the level of the tanks which supply the liquor to the cistern. These vents can therefore always be kept open to allow any air in the cistern to escape freely.

The liquor inlet pipe comes from a piece of plant which acts as a liquid switchboard and which is called, at Plaistow, an " organ." An organ consists of horizontal manifolds, one to each liquid that the char may have to take, and the number of flanged outlets on the manifolds is equal to the number of cisterns in the group. It may be cheaper in piping to have several small organs instead of one big one. The largest organ we have is the Goldie organ which feeds thirty-six cisterns with nine different liquids. In some refineries there are no organs. All the supply pipes run all round the cistern house so as to come within reach of each cistern.

An organ should not be worked by valves. Valves can leak, so that liquors and waters can get mixed up. By looking at a valve it is not possible to tell at a glance whether it is shut or open. In all our organs the connections between the horizontal manifolds and the row of cistern pipes below the manifolds are made by means of copper bends. The manifold branches not in use are closed by cocks. This system has three outstanding advantages. First, it is impossible for any cistern to be taking more than one liquid at a time. Second, the men in charge of the process can see at a glance what liquid every cistern is taking. Third, all leaks are visible. The advantages of one central organ are that control is easier and all leaks are concentrated in one place.

The number of manifolds in an organ depend on the number of liquors, syrups and waters that must be put on to the cisterns. If we were building a new cistern house for liquor now we should probably put eleven manifolds into the organ. One for liquor, two for syrups, two for lights battery, two for water battery, one for cold water, one for hot water and two spares for experiments and possible changes in method.

All our old cisterns are made of cast iron plates bolted together. Cast iron has the advantage that sugar liquors do not easily dissolve iron from the cast metal, but the many joints are a constant source of leaks and trouble. Our newer cisterns are of steel, welded without any joints. As acid liquors tend to dissolve iron from steel these cisterns need to be lined. Iron is a very undesirable impurity in a sugar liquor. It gives an unpleasant taste to golden syrup and a bad colour to yellow sugars.

PACKING THE CISTERN.

When an empty cistern is to be filled with fresh char, the sterilised sheet is laid carefully over the false bottom. Some char is then run into the cistern and a man goes in and levels this char over the sheet so that there is an even layer of char two to three feet deep. Water is then run on to this char to wet it thoroughly. This is called " packing " the cistern and takes about an hour and a half. The cistern is then ready for " settling," which is the operation of filling the cistern with char and getting the liquor thoroughly soaked into all parts without leaving any air pockets or any patches of unwetted char. The reason for wetting the packing char is that it has been found that this prevents char dust from running out with the first lot of liquor—a tiresome thing that otherwise often happens when the char is packed dry. There are many methods of settling. Three methods are used at Plaistow in different parts of the char plant. These will now be described with the reasons why different methods are used.

LIQUOR SETTLING.

Liquor settling is the best of all methods of settling because it wastes no time ; it makes no light liquors and is nearly fool-proof. We use it for all our liquor chars.

After the cistern has been wet packed, the water in the packing char is drained off. The cistern outlet is closed, and brown liquor is run into the cistern until it is rather more than half full. The char is then run into the cistern. The amount of liquor run in is such that when the cistern is full of char it is also full of liquor.

If char is run into a cistern through a single spout it forms a heap under the spout. The large grains run down the sides of the

heap and the dust and small grains will form a sort of core down the middle of the heap. This separation of char grains is undesirable. The liquor will find the path down the middle of the heap more difficult and will run for preference down the outside through the coarse grains which have the least surface. In order to reduce this grain separation and minimise the " channelling " a spreader (sometimes called an " octopus ") is used into which the char from the filling spout runs. The spreader breaks the stream of char up into a number of small streams. When char is run into liquid the grain separation is much less than when the char is run in dry. So that by liquor settling and using the spreader there are two aids to even filling.

When the cistern is full, the cover plate is bolted on to the top of the cistern and the liquor is turned on. The outlet is opened and decolourised liquor runs out of the bottom. Although the liquor at the bottom of a liquor-settled cistern has not run through more than two or three feet of char, it is satisfactorily charred because it has been lying in contact with the char for the three hours or so taken in settling the cistern. We find that the first two or three hours run of a liquor-settled cistern is almost as good as the fourth or fifth hour when the liquor has passed through the full depth of char. A liquor settled char is ready to run to the pans about three hours after packing.

WATER SETTLING.

Syrups which contain a lot of invert, like golden syrup, must be charred at a low temperature to prevent destruction of invert and to secure the removal of iron. These cisterns are therefore settled with cold water. After the cistern has been packed, it is filled rather more than half full of cold water. The char is run in through the spreader. The water is then run down until the top of the char is " bared," the bottom valve is shut and after the top cover has been bolted on syrup is run on to the cistern. The advantage of this method is that the char is all thoroughly wetted, that the char can be washed before running liquor or syrup, a practice we some-times adopt, but a considerable quantity of light syrup is made.

DRY SETTLING.

In some of our syrup chars we often have, for practical reasons of charhouse convenience, to burn and fill a cistern when we have no syrup with which to settle it. We therefore cannot syrup settle, we do not need to water settle, so we dry settle. After the cistern has been wet packed it is filled up with dry char. When the cistern is needed the syrup is run in and the air is displaced and the char wetted slowly and rather haphazardly. The cistern must be allowed to " blow " for about two hours after it is full to get rid

of the air. Dry settling is a poor method of settling a char, and the number of cisterns that we dry settle is small. It takes about five and a half hours to dry settle a char after packing.

LIQUOR CHARRING.

Brown liquor is run over the char so that the average liquor coming off is of the quality needed to give the standard quality of white sugar. Certain limits of colour and ash are laid down for the fine liquor. Some of the cisterns newly put on are giving liquor of much better quality than those that have been on a long time. Experience has shown at what point to stop the run on liquor in order to keep the average quality up to standard. With some raw sugars the ash becomes excessive while the colour is still good. With others the colour falls off while the ash is still low. When the limit, in either colour or ash has been reached the liquor bend on the organ is disconnected and the syrup manifold is connected up.

EXHAUSTING THE CHAR.

The work done by char in colour and ash removal is dependent on the amount of char used and the time of contact between the liquor and the char. When liquor is run over char at a certain rate there comes a point when the char is not doing sufficient work to make a good enough liquor. If the char is then revivified much of its working capacity is lost. It could still do a lot of decolourising and ash-removal. It is a common practice to continue to run liquor over such a partly exhausted char and to bring the resulting second-rate liquor up to quality by passing it over another char cistern. This is unnecessary as a rule. The first char can be exhausted by running the liquor more slowly when the quality of the liquor will be improved in proportion to the reduction in rate. If a dark liquor is run over a cistern to give a poor charred liquor, and if this liquor is run over a second cistern, exactly the same result is obtained much more simply by running the original liquor over both cisterns together at half the rate. We have proved this time after time. Tonnage of char and time of contact are the two factors that count.

There is a practical argument against slowing the rate progressively in order to keep the liquor quality constant. Such a method of working requires constant care and attention, and there are all kinds of opportunities for mistakes.

When a char is partly exhausted it will still take impurities out of liquor that contains a lot of impurities. We therefore follow our liquor with lower analysis syrups until the char is so exhausted that it is not worth while running it any longer.

When char has done work for many months it cannot be revi-

vified back to its original usefulness. It is customary to keep the char in two or three " stocks " according to their age. The new char is always put into the best stock and the older stocks are kept replenished by additions from the stock above. The best quality liquors are put over the best stock, and the worst stock is used for charring the lowest analysis syrups. It is not certain that there is any real virtue in this method, and one large stock of all one quality of char taking all liquors and syrups may well be as good from a charring point of view ; it would certainly be much easier from a practical working point of view. We are working towards this arrangement as the years pass. The three stock arrangement is necessary where char is put out as being spent ; but where removal of dust by riddles and removal of heavy useless char grains by Kipp-Kelly separator is sufficient, a one-stock arrangement can be worked.

" STARTS " AND " RATES."

A group of char cisterns is worked as a smooth-running unit with cisterns being filled, running liquor, washing and burning at regular intervals. The control of the whole cistern house is based on two variables only—the " starts " and the " rates." By " start " we mean the time between putting on one fresh cistern and the next. A group of cisterns is said to be on six-hour starts or eight-hour starts when a fresh cistern is put on every six or eight hours. The shortest start that can be worked depends on how fast the kilns can burn the char. The " rate " is the speed of running the liquor through the cistern. The rate can be expressed in all kinds of ways : as gallons per minute, or as cubic feet per hour, or as inches on the rate boxes on the cistern outlets, or as we say at Plaistow the " rate." The Plaistow rate is the time in hours taken for liquor to pass through the cistern. A three-rate means that the liquor passes through the cistern in three hours. The cistern capacity divided by the rate gives the flow in gallons per hour.

Consideration of the actual working of a cistern house will help to clear up any difficulties regarding starts and rates. We will take a char house having six kilns and twenty-four cisterns. If they are Buchanan kilns, one kiln will burn one cistern of char in thirty-six hours. As there are six kilns, one cistern of char can be burnt every six hours. So that it will not be possible to work the cisterns on starts shorter than six hours.

> *Rule 1.* The shortest start that a char house can work is the time in hours that one kiln can burn one cistern divided by the number of kilns.

Roughly speaking the general rule about starts and rates is : Starts control the quality ; rates control the quantity, assuming, of course, that all cisterns are kept in constant use. Starts and rates

are somewhat interdependent, as will be clear shortly.   At first thought it might seem that by shortening the starts more cisterns would be put on liquor with an increase in output. But it is not so ; actually the reverse is the case.   The number of cisterns running liquor for various starts can easily be worked out. (For simplicity syrups will be ignored and will be included as liquor. This in no way affects the argument and makes for simpler explanation.)

If there are 24 cisterns at 6-hour starts it means that each cistern will go through its full cycle in 144 hours.   That is to say, the number of cisterns in use multiplied by the start, because cistern No. 1 starts at a certain time, cistern No. 2 starts 6 hours afterwards, cistern No. 3 starts 12 hours after No. 1, and so on until 144 hours have elapsed before all 24 cisterns have been put on, and it is the turn of No. 1 again.   If the cisterns are on 8-hour starts each cistern will turn round in 192 hours.

Rule 2.   The length of the total cycle of a cistern is the number of cisterns in use multiplied by the start.

So that lengthening the start lengthens the time the cistern will run, and shortening the start shortens the time each cistern will run.

The operations of washing the char, emptying and filling the cistern take a constant time.   Assume that these operations together take 48 hours (though great variations in washing time with different methods of washing can take place).   On 6-hour starts the cisterns will be running liquor for $144 - 48 = 96$ hours, while on 8-hour starts the cisterns will run liquor for $192 - 48 = 144$ hours.

Rule 3.   The number of hours on liquor is the total time of the cycle (found from Rule 2) less the time taken for washing, emptying and settling.

The number of cisterns running liquor on 6-hour starts will be 96 divided by 6, which is 16, because the oldest cistern will have been running liquor for 96 hours (from Rule 3), the next oldest for 90, the next oldest for 84, and so on until the sixteenth cistern will be found to have been running for 6 hours.   The number of cisterns running liquor on 8-hour starts will be 144 divided by 8, or 18.

Rule 4.   The number of cisterns running liquor is the time on liquor divided by the start.

or   The time on liquor is the number of cisterns running liquor multiplied by the start.

It is now clear that lengthening the start gives more cisterns running liquor.   This must be so on general principles, because the longer start gives a longer cistern cycle, when the washing, emptying

and filling time will be a smaller proportion of the whole run.

When the brown liquor is of good quality the start can be lengthened. This gives more cisterns running liquor, so that, for the same output, the rate can be reduced. This in turn improves quality and exhausts the char more thoroughly. It is of great importance to strive always to maintain the longest possible starts.

Increase of rate gives more output, but the faster running will give a worse liquor calling for shortened starts. Shorter starts gives fewer cisterns running liquor necessitating another increase in rate. The maximum output from a char department must be when the cisterns are on the shortest possible start that the burning power of the kilns will allow, with the rate so speeded up as to give the maximum of liquor within the limits of quality. But it is obvious that the whole plant is not working nearly so efficiently as when the starts can be lengthened, the rate reduced and the char exhausting itself.

SWEETENING OFF.

After a cistern of char has exhausted its powers of removing ash and colour it has to be revivified. Before this process can begin the sugar must be washed off the char.

When the cistern is ready for washing, the liquor is shut off the top of the cistern and the liquor is run down until the top of the char is " bared." Hot water is then turned on to the top of the cistern. The object of baring the char is to prevent the liquor that occupied the empty space at the top of the cistern being mixed with water. There are several hundred gallons in this space, and if the water were put on with this liquor in the top of the cistern, a great quantity of water would be used, which would simply mix with this liquor and make lights, to be evaporated later.

When the top of the cistern is full of water the outlet is opened and the incoming water drives the liquor in front of it off the char. At least, that is what is supposed to happen ! There are always some channels in a cistern. By channelling we mean some parts of the char offering an easier path to the liquor than others. The water passes down through these channels, and it is a long time before the denser parts of the char are reached and washed clear of sugar by the water. It takes at least three hours before the first of the water can reach the cistern outlet. For the first three hours after the " top " has been put on the char (as we at Plaistow describe the putting on of water) full weight liquor will run off the bottom. After the water has started to come through it is many hours before all the sweet is off. The Brix gets gradually less. As soon as the Brix gets lighter some of the adsorbed ash begins to come away in these " char lights." These lights must be saved

because they contain a lot of sugar. But it is difficult to find a use for them without deliberately evaporating them. Some can be used for reducing syrups or for sluicing presses. Some can possibly be used for washing raw or recovery machines. But there are always too many for process comfort.

As the lights get lighter the proportion of ash in the solids in them gets greater and the proportion of sugar gets less. As soon as the analysis of the solids in the lights becomes lower than the analysis of molasses they must be thrown down the drain, although they may still contain quite a quantity of sugar. The reason for this is that every pound of ash taken into the process that does not find its way down the drain goes out as molasses, when it carries with it from 4 to 5 lb. of sugar. If char lights have such a low analysis that there are 2 parts of sugar to 1 part of ash, these lights will, if taken into the process, eventually be discarded as molasses, and at least two extra pounds of sugar will be taken away by the pound of ash. (See Chapter 14., page 285, for more information on molasses.) Actually the lights may have to be turned to drain before the analysis reaches that of molasses because from the value of the sugar in the lights we must deduct the cost of evaporating them. Periodic calculations, taking into account the cost of evaporating the lights, the value of sugar and the value of molasses must be done to determine the point at which it pays to put lights to drain. We put lights to drain at between 1° and 2° Brix., the usual figure being 1·8° Brix.

The foregoing remarks apply to low analysis lights and char water taken into the process. It may well be profitable to evaporate these waters, which have an analysis approximating molasses, in multiple effect and to sell the resulting product as molasses. Owing, however, to the large amount of ash in lights or char water, much trouble is experienced with scale on the evaporators in which they are thickened up.

THE LIGHTS BATTERY.

A large amount of light liquors or " lights " are made when washing the sweet off a char cistern. By using the lights off one cistern to sweeten off another a great saving can be made. Of course, a larger quantity of lights will come off the second cistern, but they will be at a higher Brix than off the single cistern. The total amount of water in the lights will be considerably less than before. But this putting all the lights from one cistern on to another cannot go on indefinitely because there would soon be an unmanageable number of cisterns in the battery. Some lights must be taken away, but they can be the heaviest portion. When working two cisterns in lights battery we find that we need only take the lights from full weight down to about 45° Brix out of the char house into

the process. These are used for reducing the supersaturated syrups off the granulated centrifugal machines down to saturation. All the remaining lights from 45° Brix down to 1·8°, are used in battery to sweeten off other chars.

The more cisterns in battery the higher is the Brix of the lights that must be taken away. There are certain practical difficulties in the way of having many cisterns in battery. Sweetening off with water that is already sweet must take longer in time than sweetening off with water. So that the more cisterns there are in the battery the more time will be taken in sweetening off. The lights are ideal breeding grounds for bacteria, and the less lights there are circulating round the char house the better. It is necessary to blow open steam into the lights between each cistern in the battery to kill the bacteria. This steam also keeps the lights warm.

It is difficult to say just what the lights battery has saved. There are no lights below about 45° Brix, but the quantity from full weight down to 45° is greater than without battery. The analysis of the lights from battery is distinctly better than the average analysis for ordinary lights. At Plaistow we are so used to the benefits of lights battery that we rather take it all for granted. It is only when we have to break the battery, due to bacteria or slow running, that we realise what we have been saving, because we get swamped with lights for which we have no home.

The lights battery works as follows. When we speak of two cisterns in battery we mean that two cisterns instead of running out into the process are running on to other cisterns. There are actually three cisterns connected together. Consider three cisterns, 7, 8 and 9 (Fig. 79, page 277.) Cistern 7 is taking water. The lights coming off 7 go on to 8. The heavier lights coming off 8 go on to 9 until the lights coming off 7 are down to 1·8° Brix. The rate must be so adjusted that this happens at the times of starts. On a six-hour start the rate of the battery must be such that if lights are put on to a full weight cistern at six o'clock, the lights coming off the lightest cistern in the battery will be down to 1·8° Brix at twelve o'clock. When on an eight-hour start the battery rate must be reduced until the same result is obtained in the longer time. By experience we find that when there are two cisterns in battery—that is, two cisterns feeding their lights on to their neighbours—when cistern 7 is down to 1·8° Brix, cistern 9 will be down to about 45° Brix.

Occasionally a cistern channels and will not sweeten off properly. When this happens the whole battery gets upset because when the cistern should be down to 1·8° Brix it may only have reached 5° Brix. We then have to break the battery and sweeten off in the ordinary way, making " light " lights, much to our embarrassment.

The greatest benefit of lights battery is that less ash is brought back into the process. The only lights sent from the char house to the process are from full weight down to 45° Brix. The analysis of these lights is appreciably better than the average analysis of all lights from full weight to 1·8° Brix. It might be thought that as the ash is washed out of cistern 7, the oldest in the battery, it would pass through 8 and 9 and appear in the full weight to 45° Brix lights. But low analysis lights put on to another cistern do not wash the ash readily out of that cistern, so that the ash accumulates in the char that is being washed with lights and is washed out later in the water. Lights battery therefore effects a concentration of impurities.

It should be clear that a change over from liquor to lights or lights to water can only take place when a new cistern has been put on liquor. There is no vacancy in the scheme at any other time.

Rule 5. Every run in lights battery must be one whole start.

Each cistern in the battery changes to the position of its next older neighbour every start.

WASHING OFF.

The first part of revivification consists of washing the adsorbed ash off the char with hot water. Washing off takes a long time and uses a lot of water. The time taken is from twelve to twenty-four hours or more, depending on the amount of ash to be washed out and the speed of washing. Much time can be saved by washing fast. Some water can be saved by washing slow. As the washing proceeds the water coming off contains less and less ash; and the final water is fairly pure. Some of this later water can be brought back for use in the process without great harm. But it is wrong sugar refining to melt or reduce syrups with water containing ash, so long as distilled water is available.

It may pay to take char water to the boilers, provided it is free from sweet. Sugar decomposes in a high pressure boiler into acids that may corrode the boiler steel. Char water may be very costly in softening chemicals.

THE WATER BATTERY.

Towards the end of the washing of a cistern, the water coming off is so good that it can wash a lot of ash off a cistern that is near the beginning of its washing. Towards the middle of the washing, the water off is so good that it can be used for " topping "—that is sweetening off—a cistern at the beginning of its run into lights battery. This is what is done in the water battery. The water
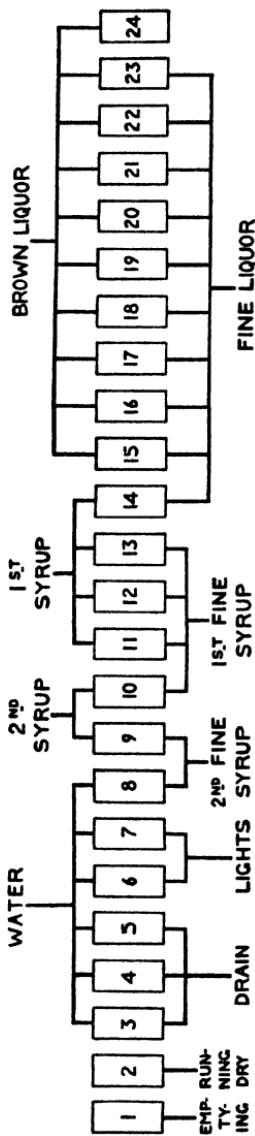
Fig. 75.
Six o'clock—Start.

Fig. 76.
Nine o'clock.

Fig. 77.
Twelve o'clock—Start.

Twenty-four cisterns on six-hour starts—no battery.
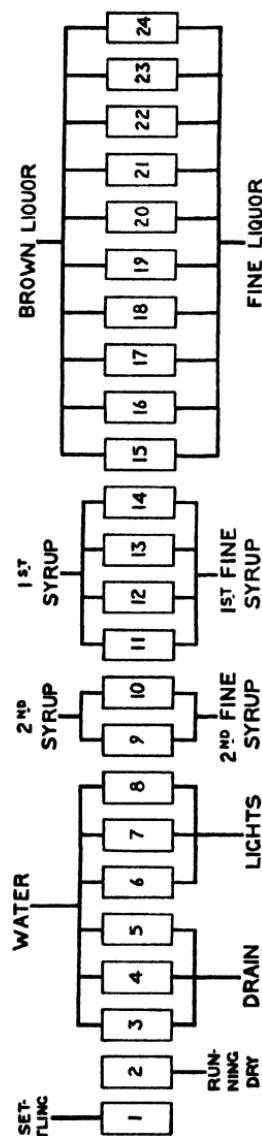
Fig. 78.

Six o'clock—Start.

Fig. 79.

Nine o'clock.

Fig. 80.
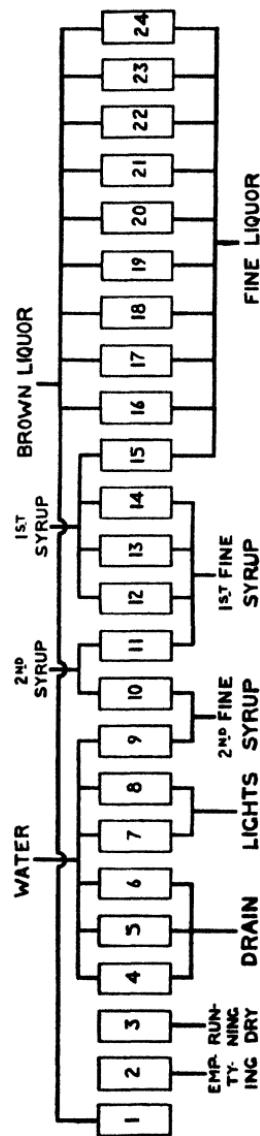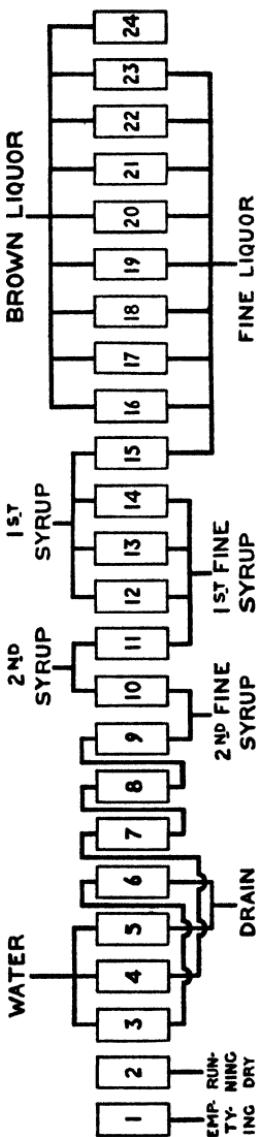
Twelve o'clock—Start.

Twenty-four cisterns on six-hour starts—two cisterns in lights battery, two cisterns in water battery.
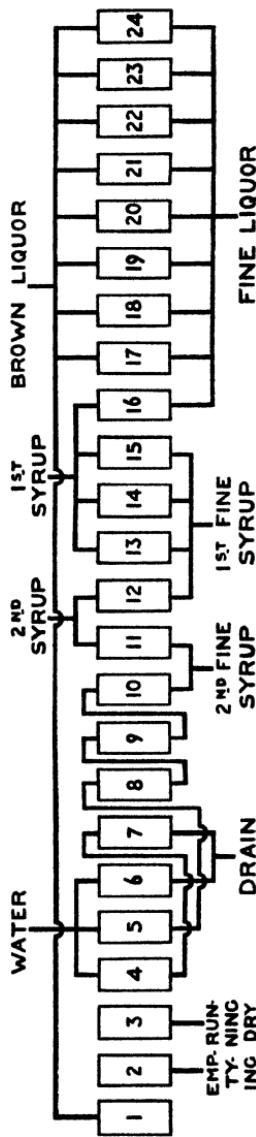
battery is not quite so simple as the lights battery, and the water battery is not one single battery like the lights battery, but is really two batteries running side by side. It works like this :—

We have considered three cisterns, 7, 8 and 9, forming a lights battery. The three cisterns next older than them are cisterns 4, 5 and 6, of which 4 is the oldest. All three cisterns are taking water. When cistern 7 comes down to 1·8° Brix it is turned to drain. Its water is full of impurities. At this time cistern 6 is also running to drain and has been doing so for the last start. Its water is also full of impurities, but is not so bad as the water off 7. Cistern 5 has been running to drain for two starts, and its water off is poor but is capable of taking up a lot of impurities, so the water off cistern 5 is put on to cistern 8 and is thus used to " top " the lights battery. Cistern 4 has been washing for three starts, and the water coming off it is fairly good and can take up a lot more impurities. The good water from cistern 4 is used to wash cistern 7 to drain (see Fig. 80.) If the high ash water had not to be discarded to drain, the water and lights batteries could be combined into one simple battery. But the greatest concentration of impurities occurs just after the sweet is off so that this is the water that must be wasted. That is why it is necessary for cistern 5 to skip two cisterns and go on to cistern 8, and for cistern 4 to skip two cisterns and go on to cistern 7. Fair water is put on to lights. Good water is put on to bad water and bad water goes down the drain. The water battery saves hot water from going down the drain ; it does not improve the lights analysis, nor does it save evaporation. The lights battery saves water and evaporation and concentrates impurities into the water to drain, thus improving the lights to process.

STARTS AND RATES IN BATTERY.

The positions of a cistern in battery can only be changed at intervals of one whole start, because all the cisterns in all batteries must be changed together. There is no vacancy for a change until a new cistern has been put on liquor when all the cisterns must move one up.

Having arranged the number of cisterns that can work in a battery, this number must be retained until the battery is broken, and the rate must be adjusted to effect proper sweetening off. As the lights battery takes water from one cistern in the water battery, the rate of the lights battery controls the rate of one part of the water battery. Proper washing off must be ensured by adjusting the rate of the water battery and/or of the rate of the cistern or cisterns running direct to drain.

Rule 6. Cisterns washing direct to drain can do so for any whole number of starts.

Rule 7. Any cistern taking liquor, any cistern taking syrup, any cistern washing direct to drain, and the two first cisterns in each part of the water battery can have their rates varied without having any effect on each other or on the battery.

THE LIQUOR " ROOM," " GALLERY" OR " PASS."

At the outlet of the char cisterns some kind of liquor switchboard, similar to the organ at the top of the cisterns, is needed. It is the practice in many char houses to place this outlet arrangement level with the top of the cisterns. The reason for this is to make certain that the cisterns never run partly dry, or " bare " their tops. If this " baring " occurs air gets into the char and may cause channelling. With better means of communication, level indicators, telephones, etc., the danger of emptying the tanks supplying the cisterns is so diminished that nowadays it is quite practical to have the cistern run off below the bottom of the cisterns, a practice that has been in use at Plaistow for over twenty years, and one which enables full advantage to be taken of the head of liquor from the tanks and so to run the chars very much faster.

The liquor " room," " gallery " or " pass " contains the outlet pipes from each cistern arranged in a vertical row. Below these run the gutters, one for each of the liquors or waters into which the cistern output must be classified. The number of gutters vary in different refineries. At Plaistow there are thirteen gutters. One for fine liquor, three for fine syrups, two for lights battery, two for water battery, one for lights to process, two for water to process, one for water to drain and one spare. Each cistern outlet runs into a " rate box." This is a long narrow open-topped metal box set across the gutters. Near one end of the box is a division plate in which is an adjustable sluice. Beyond the sluice is the outlet which can be put over any one gutter. The sluice is set for the rate at which it is desired to run and the valve on the cistern outlet is set to keep the rate box three parts full.

The gutter that takes the char water to drain should not be connected direct to drain, but should lead into tanks which can be tested for sweet before the water is allowed to run to waste. The liquor run-off is a complicated affair. At Plaistow there are forty-two cisterns running into thirteen gutters, or 546 possible positions for the rate boxes. Mistakes must occasionally occur.

CHAPTER 14. RECOVERY.

If we recover that, we're sure enough.

SHAKESPEARE—Two Gentlemen of Verona.—1595

Affination—Recovery—First and Second Crop Yields—Double Spinning—Seed—Third Crop Yield —Molasses—Melassigenic Effect—"Ideal" Molasses — Crystallisation of Molasses Sugar — Reheating — Spinning Recovery Sugar—Added Ash.

AFFINATION.

Raw Sugar consists of sucrose crystals of fairly high purity covered with a film of low purity syrup. The adhering film of syrup contains most of the impurities, but some impurities are inside the sugar crystals. During crystallisation in the pans of the raw factory, impurities are adsorbed on to the surface of the crystals. As crystallisation proceeds these adsorbed impurities are covered with a layer of sucrose. The new surface thus formed then adsorbs some more impurities, which in turn get covered with another layer of sucrose. The more impure the liquor from which the crystals were grown the more impurities are adsorbed into the crystals. The surface of a sugar crystal is small compared to, say, a grain of char, and the total amount of impurities adsorbed on to successive layers of crystal is comparatively small.

If the adhering film of syrup could be removed from the crystals a great step in the refining process would have been taken. This is what we try to do in the affination process.

Affination consists of mixing the raw sugar with a syrup which is just at saturation point and allowing the resulting magma to soak for a time during which it is stirred. The added syrup softens the syrup film, which is adhering to the sugar crystals and gradually the adhering syrup mixes with the added syrup. The magma is then run into centrifugal machines which throw most of the syrup off. But all the crystals still have a coating of syrup. A spray of hot water is used to wash this film off, but this washing is only partly successful. It washes much of the syrup off those crystals on the inner wall of the machine, but it also dissolves a quantity of sugar from these crystals. By the time it reaches the outer sugar nearest the machine cloth, it is nearly saturated and is very much more viscous—that is, stickier—so that it is not able to wash the outer layers of sugar.

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The syrup thrown off the crystals is called "raw syrup," and the syrup thrown when the wash water is applied is called "raw washings." In some refineries these syrups are called "affination syrups." Either raw syrup or raw washings is used for making the magma with the raw sugar. Theoretically the washings should be used for making the magma, because they are of a higher analysis than the heavy syrup. As affination is a separation of low syrup from washed crystals a better separation results if the syrup taken away from the process is as low in analysis as possible. Therefore raw syrup should be taken away and the washings used for putting back into the magma. In practice, however, there is never nearly enough washings to make the magma. The washings only amount to about one-third to one-quarter of the amount required. The difference between the analyses of magma made with washings made up to quantity with raw syrup, and magma made with an unseparated mixture of raw syrup and washings, is so small that it is outweighed by the practical advantage of not attempting separation. For many years we separated the raw syrup from the washings, but we now run them in together with a great simplification of the process.

Certain points are now clear. It is desirable to use the smallest possible quantity of wash water, because all this water will saturate itself with sugar which all has to be recovered later. In order to limit the wash, plenty of time should be given to the magma syrup to soften the syrup film on the raw sugar crystals. This means that the magma mixer should be large and provided with stirring gear which stirs slowly in order not to break the crystals. The viscosity, or stickiness, of the magma syrup should be as low as possible. This means that the magma should be heated up considerably. None of our magma mixers are provided with sufficient heating arrangements, and we never get our magma more than warm.

RECOVERY.

Recovery is the process of recovering the sugar from the raw syrup and washings that we have dissolved in the affination process. If there were no affination, there would not need to be a recovery process. The actual molasses in a raw sugar is about 5%, but the amount of raw syrup and washings is between 15% and 20%. The difference is sugar that must be recovered.

Recovery consists of boiling the raw syrup and washings in vacuum pans and rejecting a final syrup, called molasses, from which we cannot economically recover any more sugar. For many years we did our recovery in two boilings. When melting 100% beet sugar we have successfully effected recovery in one boiling. But nowadays we always do three boilings. As will be seen shortly we

do not boil all the syrup three times ; in fact when we are doing good recovery work, although using three boilings, the syrup is only boiled rather less than two and a half times.   These three boilings we call first, second and third crops.   Much of the sugar world calls them the A, B and C boilings.

FIRST AND SECOND CROP YIELDS.

There are all sorts of ways of working a recovery house, but one point which is independent of the particular method of working

RAW SYRUP
100 (3·1)

1ST CROP MASSE
80 (3·1)

10 (3·1)

40% yield

1ST CROP SUGAR   1ST CROP SYRUP
32 (0·2)   48 (5·1)

2ND CROP MASSE
58 (4·7)

40% yield   10 (3·1)

2ND CROP SUGAR   2ND CROP SYRUP
23 (0·4)   35 (7·5)

3RD CROP MASSE
45 (6·5)

45% yield

3RD CROP SUGAR   MOLASSES
20 (0·6)   25 (11·3)

Amount of masse boiled   183
Actual number of boilings   2·7
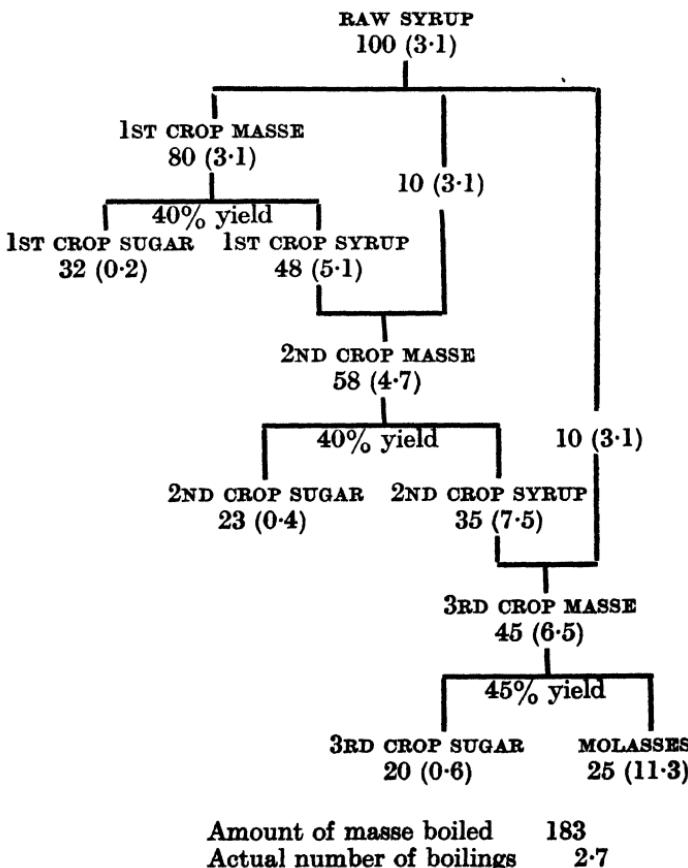
Fig. 81.
Recovery with poor first and second crop yields.

is important for clear thinking in recovery work. The amount of impurity to be eliminated in the molasses from the third crop boiling has nothing to do with the internal arrangement of the process in the recovery house ; it depends only on the raw sugar analysis. The aim of any recovery process plan inside the recovery house is simply to enable the molasses thrown from the third crop masse to be well exhausted and easily separated from the sugar crystals. It has been found in practice that the amount of sugar to be recovered from the third crop should be as small as

RAW SYRUP
100 (3·1)

1ST CROP MASSE
60 (3·1)   20 (3·1)

50% yield

1ST CROP SUGAR   1ST CROP SYRUP
30 (0·2)   30 (6·0)

2ND CROP MASSE
50 (4·8)   20 (3·1)

50% yield

2ND CROP SUGAR   2ND CROP SYRUP
25 (0·4)   25 (9·3)

3RD CROP MASSE
45 (6·5)

45% yield
3RD CROP SUGAR   MOLASSES
20 (0·6)   25 (11·3)
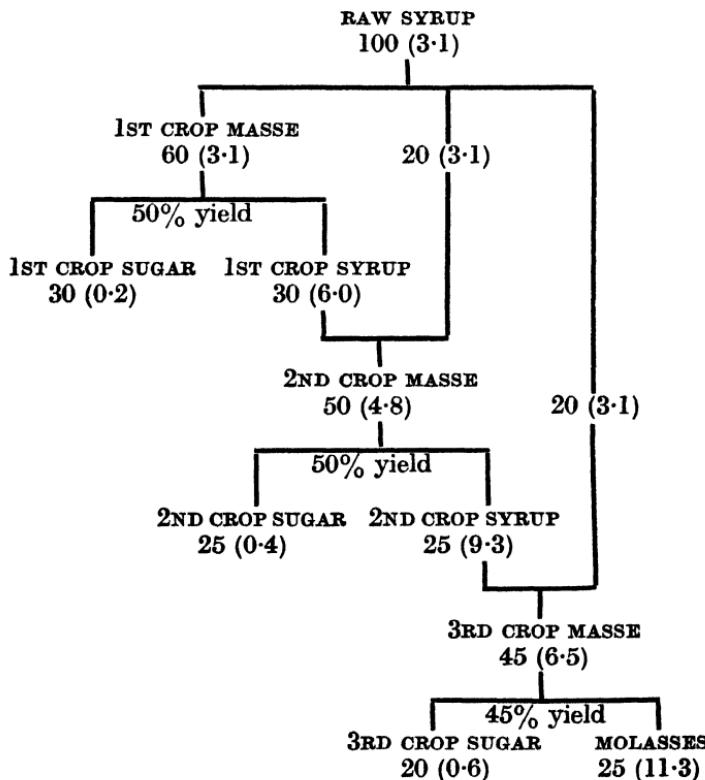
Amount of masse boiled   155
Actual number of boilings   2·4

Fig. 82.
Recovery with fair first and second crop yields.

possible, and that the grain should be as good as possible in order that the molasses may leave the sugar freely in the machines. From this it follows that the analysis of the second crop syrup which forms the bulk of the drinks in the third crop pan should be as low as possible, and that a good grain should be started on a footing of fairly high analysis syrup. Everything that is desirable in good recovery work is helped by obtaining the highest possible yields from the first and second crops.

Figs. 81 and 82 show two possible examples of recovery working, using the same plan of work. They are examples only, not necessarily the way in which we may be working. The open figures represent dry solids and the figures in brackets are the percentages of ash. In both examples the third crop yield and molasses analysis are given as being the same. This is unlikely because in Fig. 82 the amount of raw syrup available for starting the third crop skipping is 45% so that a very good grain should be started, whereas in Fig. 81 the amount of raw syrup available for footing the third crop is only 22%. This should increase the third crop yield and slightly improve the molasses exhaustion on the good yield example in Fig. 82.

It will be seen that, in Fig. 81, where the yield of the first two crops was only 40%, the amount of first and second crop masses boiled was 138 parts. When the yield of the first two crops is increased to 50%, as shown in Fig. 82, the amount of masses boiled in these two crops is reduced to 110 parts. The extra work done with the low yield means 7% more steam, 15% more pan capacity, 15% more centrifugal machines and men to work them. The most important disadvantage of low recovery yields probably is that the more often low syrups are boiled the more difficult they become to work, the greater is the inversion and sugar destruction. In the example shown in Fig. 81 30% more syrup is boiled three times and 16% more syrup is boiled twice than in the scheme shown in Fig. 82.

DOUBLE SPINNING.

In order to get the greatest possible yield, it is important to use the least possible amount of water for washing the crop sugars. But crop sugars are often very difficult to handle and cry out for generous washing. A great saving in wash water and a considerable improvement in crop sugar analysis and colour is obtained by double spinning. The heavy mother syrup is spun off in one set of centrifugal machines and no attempt is made to wash the sugar. The syrupy sugar is discharged from the machines into a mixer where it is pugged up into a magma and then spun in another set of machines. This arrangement ensures that the heavy syrup cannot possibly have its analysis improved by the accidental

addition of washings. At Plaistow we only have facilities for double spinning the mixed second and third crop sugars ; but at Liverpool all three crops have double spinning arrangements which is one of the reasons why the Liverpool recovery results are better than those obtained in London.

SEED.

Third crop sugars often wash up so badly that the melted washed sugar is too bad to be mixed with the affined raw sugar and thereby added to the brown liquor. It has to be carbonated and charred separately. For some years at Plaistow we have been giving the second and third crop sugars only a moderate wash, and then using these sugars as seed on which to grow the first crop grain. This arrangement means that more pan power is needed for first crop, but the pans can be boiled more quickly because they start with a fair sized grain. All the recovery sugar appears in the first crop, and bad second and third crop sugars do not degrade the brown liquor. Seeding in this way is not an ideal arrangement ; it is merely a good way of working a bad plant. Double spinning with good modern high-speed machines, possibly combined with seeding, might well be the right process.

THIRD CROP YIELD.

The yield of sugar from the third crop boiling is the most important part of the recovery process. The syrup thrown from the third crop is molasses, which is sold at a low price. This price is the same whether we put out a well " exhausted " molasses or one in which we have left a lot of sugar. It is not enough just to boil a lot of sugar out of the molasses unless this sugar will spin well in the machines. Because if it spins badly, a lot of molasses will be brought back into the process with the washings. The grain should be sharp and even. To make a good start with the graining of a third crop pan, as much high syrup should be used as possible. This is why the yields of the first and second crops are important, as explained by means of Figs. 81 and 82.

MOLASSES.

Molasses is a complicated solution of salts, organic matters, sucrose and invert in water. There comes a point in the crystallisation of sucrose from molasses where no further crystallisation will take place, however much the supersaturation be increased or the circulation of the massecuite improved. A condition of equilibrium is reached. When no more sucrose can be extracted by crystallisation, the molasses is said to be " exhausted." This exhaustion point is reached when there is still quite a high percentage of sucrose in the molasses. This percentage of sucrose which cannot be taken out of molasses by crystallisation varies with the composition of the

non-sucrose ingredients. We do not understand the exhaustion point of molasses properly, and our ideas about it are continually changing.

It is possible to remóve a large part of the sucrose from exhausted molasses by certain chemical processes. These processes are not very successful in the presence of invert sugar, and are principally applicable to beet molasses. The best known of these processes are the lime process, the barium process and the strontia process. All work on roughly the same principle. If the molasses is made very dilute, 10° to 15° Brix, and fresh quicklime is added, the lime will combine with the sucrose to form a calcium sucrate (actually calcium trisucrate) so long as the molasses is kept quite cool. The calcium sucrate is insoluble in water and comes out as a precipitate which can be filtered off. The cake of calcium sucrate is mixed with water and gassed with CO_2. This liberates the sucrose and throws down a precipitate of chalk. The great disadvantage of all these processes is that they have to be carried out at a very low Brix, necessitating a great deal of evaporation and a large plant. We do not use any of these processes.

MELASSIGENIC EFFECT.

The amount of sucrose that is held locked up in an exhausted molasses depends on the amount and proportions of invert, ash and organic in the molasses. Some non-sucrose bodies have what is known as a " melassigenic " effect. Melassigenic means molasses-making. (French, Melasse—molasses. Greek, genesis—birth.) In solutions, the effect of adding another soluble substance has a marked effect on the solubility of the original dissolved substance. For example, if common salt is added to a solution of soap in water, the salt dissolves and throws the soap out of solution as a precipitate. By adding sufficient salt all the soap can be thrown out. If salt is added to a solution of sucrose, however, the very reverse takes place. A saturated sugar solution to which salt is added will dissolve more sugar. On the other hand, invert sugar reduces the solubility of sucrose in water, but our knowledge of the effect of invert is far from complete. A solution containing salt and invert will always hold some sucrose in solution—the amount of sucrose being dependent on the proportions of salt and invert.

When we turn out a molasses we must have some way of measuring our success in exhausting it. A beet molasses may contain 55% sucrose on solids, and a cane molasses may contain 40%, yet both may be equally well or equally badly exhausted. As the years pass we alter our ideas as to the melassigenic effect of the non-sucrose constituents. Forty years ago we were satisfied with the figures upon which the " commercial net " is based. The

commercial net formula says that a molasses will contain sucrose in a quantity equal to five times the ash plus an amount equal to the amount of invert. That is to say, the melassigenic effect of ash is 5 and invert is 1. As we know that invert does not hold an equal quantity of sucrose in solution, this formula must be wrong—but the exact effect of invert, whether it is melassigenic at all or not, is not yet clear.

The molasses that we turned out, say, thirty years ago, were much lower than the figure indicated by the commercial net. We used to say we had turned out a molasses of − 12, meaning that where the commercial net had prophesied a sucrose of 60%, the molasses had in fact only contained 48%. This did not mean we were doing good work. It meant we were using a bad formula.

"IDEAL" MOLASSES.

There is no need to describe the various ways which have been tried and discarded to measure the success of molasses exhaustion since the days of commercial net. They included the " true " net, the " real true " net, the " new " net. We are at present (1940) using what we call the " ideal total sugars " formula, which already, after only three or four years' use, is proving out of date. No sooner do we devise a new formula to give us a standard for our molasses, than we make a process improvement and are able to beat the standard. Liverpool's new recovery house is regularly, week after week, beating the " ideal total sugars " by 1% to 2% of total sugars.

The " ideal " formula was devised by taking the best—that is lowest—molasses that had been produced from all kinds of raw sugars and fitting, by mathematical jugglery, a formula to suit them all. It is not a perfect formula, but it gives a very good guide as to what should be possible with our present technique and our present plant. It applies equally well to all raw sugars of any analysis within the range that we normally get ; beet or cane, Australian or West Indian. It is what is called an empirical formula. (Greek, en—in, peira—experiment.) An empirical formula is not based on a theory or sound scientific basis, but merely fits certain facts which have been discovered by experiment. Here is the " ideal " formula :—

$$\% \text{ Total Sugars on Solids in Molasses} = 55 + 14g$$

$$\text{where } g = \frac{\text{Invert}}{\text{Non-Sugars}}$$

Clearly this formula will give absurd results if g is greater than 3·2, because the total sugars will amount to more than 100%. But

within the limits that we meet in practical refinery work, namely
$g = 0$ to $g = 1.5$, the formula gives a fair measure of the success
of exhaustion of refinery molasses. For average beet sugar $g = 0$,
and for average cane sugar $g = 0.5$ to 1.0.

By means of the formula it should be possible to forecast the
analysis of the molasses thrown from a sugar being melted. This,
however, is not always possible, because in the affination process
the invert is washed off the raw sugar more easily than the ash,
which is partly adsorbed on to the surface of the crystals. This
alters the invert/non-sugar ratio in the raw syrup from which the
molasses is produced, making it higher than the ratio in the original
raw sugar. Here is a calculation of a molasses worked out by the
" ideal " formula based first on the raw sugar and then on the raw
syrup that was actually thrown from that raw sugar, compared
with the actual molasses that was made. The figures are the
average analyses for a week when melting a mixture of Cuban,
West Indian, Natal, Australian and Javan.

Raw Sugar :

Sucrose	97·93	
Invert	0·89	
Ash	0·45	
Organic	0·73	
	100·00	

$$\left.\begin{matrix} \text{Ash} & 0.45 \\ \text{Organic} & 0.73 \end{matrix}\right\} = 1.18 \qquad g = \frac{\text{Invert}}{\text{Non-Sugars}} = \frac{0.89}{1.18} = 0.754$$

Molasses by " ideal " formula :

$$\left.\begin{matrix} \text{Sucrose...} \\ \text{Invert ...} \end{matrix}\right\} = 55 + 14 \times 0.754 = 65.56$$

$$\left.\begin{matrix} \text{Ash} \quad ... \\ \text{Organic...} \end{matrix}\right\} = 100 - 65.56 = 34.44$$

Now the invert divided by the non-sugars was 0.754, so that
in the molasses the invert will be equal to the non-sugars multi-
plied by 0.754. In the raw sugar the ash/non-sugars was $0.45/1.18$,
so that if we multiply this ratio by the total non-sugars in the
molasses we shall get the amount of ash in the molasses. So that
the molasses analysis becomes :—

$$\text{Sucrose} = 65.56 - 25.86 = 39.70$$
$$\text{Invert} \ = 34.44 \times 0.754 = 25.86$$
$$\text{Ash} \quad = \frac{0.45}{1.18} \times 34.44 = 13.13$$
$$\text{Organic} = 34.44 - 13.13 = \underline{21.31}$$
$$100.00$$

Assuming that none of our subsequent processes upset the
proportions of the non-sugars and invert, this should be the analysis

of the molasses produced from this raw mixture. But as has been pointed out, the very first process, affination, upsets things. Here are the affination analyses :—

	Raw Sugar	Raw Syrup	Washed Sugar
Sucrose	97·93	82·95	99·18
Invert	0·89	7·92	0·21
Ash	0·45	3·30	0·24
Organic	0·73	5·83	0·37
Invert/Ash ratio	1·98	2·40	0·88
Organic/Ash ratio	1·62	1·77	1·57

The alterations in the proportions of the non-sucrose substances are shown by the Invert/Ash and Organic/Ash ratios which are shown underneath the analyses. If the invert, ash and organic had washed off evenly these ratios would be the same in all three analyses. Let us work out the ideal molasses from the raw syrup analysis :—

Raw Syrup :

Sucrose 82·95
Invert 7·92
Ash 3·30
Organic 5·83 } 9·13

$$g = \frac{\text{Invert}}{\text{Non-sugars}} = \frac{7·92}{9·13} = 0·86'$$

Molasses by " ideal " formula :

Sucrose
Invert $\Big\}$ $= 55 + 14 \times 0·868 = 69·14$

Ash
Organic $\Big\}$ $= 100 - 69·14 \qquad = 30·86$

Molasses :

Sucrose $= 69·14 - 26·75 = 42·39$
Invert $= 30·86 \times 0·868 = 26·75$
Ash $= \dfrac{3·30}{9·13} \times 30·86 = 11·13$
Organic $= 30·86 - 11·13 = \underline{19·73}$
$$\overline{100·00}$$

It is interesting to compare the two analyses which the " ideal " formula prophesies with the actual molasses produced.

		Ideal Molasses from Raw Sugar Analysis	Ideal Molasses from Raw Syrup Analysis	Actual Molasses Produced
Sucrose	.	39·70	42·39	39·65
Invert	. .	25·86	26·75	25·21
Ash .	.	13·13	11·13	11·74
Organic	.	21·31	19·73	23·40
		100·00	100·00	100·00

The reason why the actual molasses differs from the " ideal " that the other analyses prophesy, is because some increase in organic has taken place. This was probably due to destruction of sugar. This increase in organic has brought the total sugars in the molasses down to the figure prophesied by the " ideal " calculated from the raw sugar. But the result is not really satisfactory because only 11·74 ash has been eliminated instead of 13·13.

CRYSTALLISATION OF MOLASSES SUGARS.

It is customary to allow third crop massecuites to remain for several days in the mixer, cooling. The supersaturation of the molasses increases, due to the reduction in temperature, and extra sucrose is crystallised out in this way. This is an almost universal practice in the sugar industry. We have done experiments that indicate that much more useful crystallisation can be done in the pan than is done at present, if the masse is boiled up really tight and the vacuum raised to a high figure so as to cool the boiling masse.

In the recovery pans we control the boiling operation by means of the B.P.E. It does not really matter what supersaturations these B.P.E.'s correspond to so long as the practical results work out all right. It is impossible to make a table of supersaturations and B.P.E. for molasses because, for a given B.P.E. the supersaturation varies with the relative proportions of invert, ash and organic in any particular molasses.

Recently the sugar industry of the world has been trying many kinds of rapid cooling mixers, in which all kinds of curious gear is arranged for stirring and quickly cooling the masse. This cooling serves no useful purpose except to reduce the amount of mixer capacity needed for a given output. The reduction in time in mixer is possibly beneficial by lessening the time during which the product is kept in heat and may thereby reduce sugar destruction.

REHEATING.

As soon as crystallisation is finished there is no need for the molasses surrounding the crystals to be supersaturated. The lower

the supersaturation the lower will be the viscosity or stickiness, and the molasses will leave the crystals more freely in the machines. It is therefore desirable, before spinning the masse, to reduce the molasses to as near saturation as possible. It is, of course, important that the reduction should not be carried below the saturation point, or sugar would be redissolved.

The supersaturation can be reduced in two ways. Either by the addition of water or by raising the temperature. The addition of water is a poor way. Before the added water can be completely mixed into the molasses it must meet some crystals and partly dissolve them. Heating can be carried out so as to be absolutely free from this danger of redissolving sugar. The reheating gear must be designed with a very large surface so that it is possible to use heating water which is just at saturation temperature. If the heating medium, water or vapour, is above saturation temperature it is possible for the sugar near to the heating surface to be re-dissolved owing to the local molasses having been heated too much. If the heating surface is large, adequate heating can be carried out by pumping the warm water rapidly through the heating surface.

While we cannot make a saturation table of Brix against temperature for molasses owing to variation in the non-sucrose constituents, we can easily find the saturation temperature of any particular molasses without bothering about its water content or analysis. For the control of reheating this is all we want to know, because if we heat the masse to just below saturation temperature we have done all that reheating sets out to do.

The saturation temperature is found by means of the " Harman saturation cell." A small glass cell, in which is placed a drop of the molasses to be tested together with a few sucrose crystals, is placed under the microscope. The edge of one of the sugar crystals is sharply focussed. The temperature is then slowly raised by means of warm water circulated round the cell. Immediately the saturation point is passed, the edge of the crystal is seen to start dissolving. The temperature at which this occurs is noted and a suitable cor-rection is made for the fact that the saturation point has been over-shot. As far as reheating is concerned, nothing more is needed.

SPINNING RECOVERY SUGARS.

The separation of the crystal sugar from the syrups in recovery masses is often very difficult. The grain is often small and the syrup very sticky. Any syrup that is left adhering to the crystals must be washed off, and this washing always redissolves sugar that we have taken so much pains to crystallise. Any sugar dissolved in the washing has to be recovered by further boiling. A very great improvement is obtained by the use of high performance

centrifugal machines. The 1,600 r.p.m. Roberts machines have four times the centrifugal force produced by the old 750 r.p.m. machines.

It is important that the machining should be done quickly. Any syrup that does not come off in the first few minutes will take a long time to separate because it will have cooled down and become more viscous. Long spinning not only increases viscosity by cooling, but after much of the syrup has been thrown off, air is able to pass between the crystals and this increases the viscosity of the remaining syrup by partially evaporating it.

If the grain is mixed, the small grains may block the crevices between the larger grains. This prevents the syrup getting through the wall of sugar, and syrup collects on the inside face of the sugar. The reason why syrup collects on the inside face is because the syrup is lighter than the crystals. As centrifugal force is proportional to the weight of the rotating materials, it follows that the crystals are being acted on by a greater force than the syrup. There is therefore a tendency for them to fly outwards at the expense of the syrup. For this reason the machine cloth often gets clogged with sugar grains and prevents the syrup getting away. It is clear that the centrifugal machine is an entirely unsuitable piece of plant for the work we give it, but we have to use it for want of anything better. " Syrup on the face " is a common complaint in the recovery house. If the syrup layer is thick and the syrup has a low viscosity, the condition may be dangerous. The reason for this is rather technical and will not be given here. It is explained in Chapter 17.

Many sugar men believe that the acceleration of a recovery machine should be slow. If the acceleration is very quick it is believed that grain may be forced into the holes in the cloth and so prevent the syrup from getting away. It is difficult to see why the rate of acceleration should have any such effect. We have carried out a number of experiments on varying the acceleration rate, but have not got any results to prove one thing or another. It is possibly wishful thinking. Rapid acceleration needs a big expensive motor and a lot of power. It is probably quite true to say that quick acceleration is of no virtue in a recovery machine, but there seems to be no evidence that it is bad. It is absolutely essential to have a very high rate of acceleration in a fine sugar machine, or the syrup would have left the masse before it had taken up its position as a vertical wall of even thickness. For simplicity in spares we use the same motors for our 1,600 r.p.m. recovery machines as we do for our 1,200 r.p.m. fine sugar machines. We feed the recovery machines with a current of 57 cycles, whereas we feed the fine machines with a 42·8-cycle current.

ADDED ASH.

Ash brought into the process can only go out in three ways ; in a finished product like yellow sugar or syrup ; down the drain with the char water ; in the molasses. The outlet to market is limited by quality considerations and the capacity of the market to absorb low-quality products. The second outlet, down the drain, is the best. The goal of the sugar refiner is the elimination of impurities, and down the drain is 100% elimination. The third outlet, into the molasses, is the worst, because every ton of ash put out as molasses carries with it (owing to its melassigenic effect) 4 or 5 tons of sugar. Day in day out we can say that the ash to market will be the same. Also the ash elimination to drain is a fairly constant figure. So that any added ash will find its way into the molasses.

The following are some of the ways in which ash can be added to the process :—

(a) The neutralisation of acid liquors with soda.

(b) The softening of very hard sweet waters with soda to reduce scale on the evaporators.

(c) The taking back of char water into the process instead of eliminating it to drain.

(d) The use of hard town water for process purposes. (Hard town water should be softened and go to the boilers where the ash will be eliminated in the blow-down. The distilled water should be used in the process for melting and syrup reduction.)

(e) The excessive washing of raw sugar bags.

(f) The excessive washing of filter press cake.

All these things may from time to time have to be perpetrated, but it must never be forgotten that extra molasses will be formed, and this disadvantage must be set against any advantage it is hoped to obtain from the ash addition.

It might seem that the addition of soda for reducing the hardness of sweet waters to minimise scaling was not an ash addition because the soda merely replaces the lime. But these sweet waters will probably find their way eventually on to the char, where lime salts are adsorbed but soda salts are untouched.

The matter of eliminating ash to drain is discussed again in the next chapter.

CHAPTER 15.   LOSSES, SAVINGS & CONTROL

" Thou shalt not be the fool of loss."

TENNYSON—In Memoriam—1850.

Sugar Loss—Comparison of Losses—Method of Ascertaining Sugar Loss—
Known Sugar Loss — Carbonatation Loss — Loss in Press Cake — Loss in
Char Water — Loss in Various Drains — Loss in Condenser Water — Loss
in Wet Char to Kilns—Loss in Turning the Scale Beam—Check Weighing—
Unknown Sugar Losses — Loss due to Faulty Analysis — Loss due to Char
Adsorption—Loss due to Destruction on Char—Destruction in the Pans—
Dust Loss—Sugar Loss due to Heat—Sampling—Heat Loss—Heat Saving—
Power Saving — The Steam/Power Ratio — Waste of Packing Materials —
Breakdowns — Labour Saving — Quality Control — Melt Control — Refining
Efficiency of Various Processes—Figures and Statistics.

The principal losses in a sugar refinery are :—

    (*a*) Sugar loss.
    (*b*) Heat loss.
    (*c*) Waste of packing materials.
    (*d*) Time lost due to breakdowns.

Savings can be made in all these things and by :—

    1. Process improvements.
    2. Power improvements.
    3. Economic use of waste heat.
    4. Saving in added water.
    5. Saving in added ash.
    6. Labour saving.

Control consists of maintaining the output at the set standard
of quality with the minimum of loss and the maximum of saving.

SUGAR LOSS.

Loss of sugar occurs in every refinery.   The amount of loss
varies in different refineries from about $\frac{1}{3}$% to 1% of the sugar
melted.   The loss in T. & L. refineries varies between about $\frac{1}{2}$%
to about 1%.   We have never been as good as ·34% which is the
loss claimed by one American refinery.   Our comparatively large
loss may be part of the price we have to pay for our high quality.
It may be partly due to some of our plant being out of date and

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partly because we force a large melt through too small a plant in some of our departments.

COMPARISON OF LOSSES.

It is very difficult to compare the losses of one refinery with those of another unless it is certain that the method of ascertaining loss is the same in both places.   For example, the author has met sugar men who calculated their losses by Pol only;   others who ignored the increase in weight during inversion.   In one refinery visited the weight tolerance on packet sugars was + or − ½ oz. in a 2-lb. packet ;   that is a possible loss or possible gain of 1½% !

It is a curious but unfortunate truth that every looseness in calculation or measurement of loss gives a lower loss than that which is really taking place.

METHOD OF ASCERTAINING SUGAR LOSS.

Before considering possible sources of loss we should look briefly into the method by which we measure the loss.

By sugar loss we mean loss of total sugars expressed as sucrose. Some sugar refiners calculate their loss on polarisation.   This would be quite good enough if there were never any invert in any of the sugars or syrups in the refinery, and works well enough in a beet factory.   But in our case where one week we may be melting West Indian raws containing perhaps 2% of invert and the next week Australian containing 0·3% invert any figures worked out on Pol only would be quite meaningless.   Suppose the West Indian contained 96·0% of sucrose, then its total sugars will be 98% and its Pol will be 96·0 − (2 × ·25) = 95·5.   The Pol is 97·5% of the total sugars.   In the case of the Australian, the sucrose will probably be 99% which gives a total sugar of 99·3 and a Pol of 99·0 − (·3 × ·25) = 98·9.   The Pol in this case is 99·6% of the total sugars.   (For this example an invert polarisation factor of ·25 has been used—see page 85.)

As sugar destruction is believed to be largely invert destruction, the invert must be considered, but it will not do just to add the two sugars together and call them total sugars.   When we make and sell syrups we deliberately invert some of the sucrose, and by so doing increase the weight of the total sugars, because, as was explained on page 53, 57 parts of sucrose combine with 3 parts of water to make 60 parts of invert.   This is the same as saying that 95 parts of sucrose become 100 after inversion.   If we had 100 parts of sucrose and put out 100 parts of invert, we should, if we considered total sugars only, say that we had made no loss, when in fact we had lost 5%.

To ascertain our sugar loss we take the weight and analyses of all the raw sugar in, and all the refined products and molasses out. From these figures we get the total tons of sucrose, tons of invert, tons of ash and tons of organic taken in and put out. We correct these for the stock in process at the beginning and end of the period. From these figures we find our sucrose loss and our invert gain. (There is always an invert gain, because, apart from deliberate inversion for syrups, there is always some inadvertent inversion.) We deduct the invert gain from the sucrose loss (after correcting for the gain in weight due to inversion) and this gives us our sugar loss expressed as sucrose.

Another important figure is the amount of invert that has been made unintentionally. We work out the amount of invert that we have taken in, the amount that we have made deliberately, correct for stock differences and thus get the amount (less any that has been lost) that has been made in process in spite of our precautions.

KNOWN SUGAR LOSS.

Before any attempt can be made to find ways of preventing sugar loss it is necessary to know the size of the loss and, if possible, where it is taking place. We have never been able to find out where more than about one-third of our loss occurs. Another equally baffling fact is that the loss at Liverpool is usually only about two-thirds that which takes place in London, and we have never been able to account really satisfactorily for the difference.

We test every possible outlet for loss continuously. For example, at Plaistow there are some twenty-four drains that are tested for sweet at least every hour throughout the year ; some are tested every few minutes. The discarded filter cake is tested every two hours. The wet char to kilns is tested every day. Many times every hour the amount by which we turn the scale in our fine product is tested. A continuous watch is kept for inversion and fermentation. Despite all this two-thirds of our loss goes in ways about which we know nothing whatever.

On the next page is a statement of the Sugar Loss at Plaistow during a recent six months winter period.

Each of the ways in which known loss occurs, and some of the possible ways in which unknown losses may occur will be briefly discussed. This does not mean that these are the only ways in which losses can occur. Our loss may be taking place in some way that has not yet occurred to us.

		Tons.	%	Value.
Melt	. . .	223,756	100·000	£3,133,000
Known Losses				
Destroyed in carbonatation		40·8	·019	570
Lost in press cake .	.	31·4	·014	440
Char water to drain	.	82·3	·037	1,150
Other drain waters .	.	57·4	·026	800
Condenser water to river .		64·0	·029	895
Wet char to kilns	.	13·9	·007	195
Overweight—bulk .	.	76·6	·036	1,075
Overweight—				
. small packages	.	141·1	·067	1,975
Total known losses	. .	507·5	·235	7,100
Unknown losses	. .	1064·2	·484	14,900
Total losses	. . .	1571·7	·719	£22,000

CARBONATATION LOSS.

This has already been discussed in Chapter 12, page 254. The loss is comparatively small. It might have been considerably less had we had a better plant. With continuous carbonatation the pH can be better controlled, temperature is more constant and the process is quicker. But the advantages of carbonatation are so great that we would not discard the process even were the losses to be several times as great. The sugar loss in carbonatation consists of the destruction of invert sugar.

LOSS IN PRESS CAKE.

This loss is also a matter of relative values. We could wash our press cake much more and we could undoubtedly reduce this loss. But much more wash water would be used, and this would all have to be evaporated. This extra water would also dissolve ash out of the cake which would increase the amount of molasses that would require elimination. This has already been discussed in Chapter 14, page 293. Some form of battery press washing might help to reduce this loss. .

LOSS IN CHAR WATER.

It has been pointed out in Chapter 13 that a certain amount of sugar must be put down the drain in the char water, because, if this sugar were brought back into the process, it would be accompanied by a quantity of non-sugars which would have to be put out in the molasses. In Chapter 14 the evils of bringing ash back into the process have been pointed out.

Here is a typical analysis of the char water put down the drain from 1·8° Brix to 0·5° Brix.

Char Water Solids.

$$\left.\begin{array}{ll}\text{Sucrose} & 17\cdot9 \\ \text{Invert} & 21\cdot6\end{array}\right\} 39\cdot5$$

$$\left.\begin{array}{ll}\text{Ash} & 33\cdot0 \\ \text{Organic} & 27\cdot5\end{array}\right\} 60\cdot5 \qquad \frac{\text{Invert}}{\text{Non-sugars}} = \cdot357 = g$$

$$\overline{100\cdot00}$$

Water   99·02

An "ideal" molasses with the non-sugar proportions the same as in the above analysis would have the following analysis :—

$$\left.\begin{array}{l}\text{Sucrose} \\ \text{Invert}\end{array}\right\} = 55 + 14 \times \cdot357 = 60$$

$$\left.\begin{array}{l}\text{Ash} \\ \text{Organic}\end{array}\right\} = 100 - 60 \qquad = 40$$

This gives :—

Sucrose = $60 - 14\cdot3 = 45\cdot7$

Invert $= 40 \times \cdot357 = 14\cdot3$

Ash $= \dfrac{33\cdot0}{60\cdot5} \times 40 = 21\cdot8$

Organic $= 40 - 21\cdot8 = \underline{18\cdot2}$

$$\overline{100\cdot0}$$

Let us increase the figures in this analysis in the ratio 40 to 60·5, which will bring the non-sucrose figures up to the quantities in the char water analysis :—

	Molasses made from Char Water.	Char Water Solids.	Difference.
Sucrose . .	69·2	17·9	51·3
Invert . .	21·6	21·6	0
Ash . .	33·0	33·0	0
Organic .	⁓27·5	27·5	0

The difference of 51·3 of sucrose is the extra sucrose that would be carried away by a molasses containing 100 parts of char water solids. In order to save 17·9 of sucrose from going down the drain, the molasses made by bringing back char water into the process will carry away 51·3 of sucrose (as well as the 17·9) in the molasses.

It is now quite clear that if any char water or char lights, which have an analysis lower than molasses, are brought back, they must be kept out of the process. The only possible way of dealing with them is to evaporate them up to molasses weight and sell them as

molasses without letting them take up valuable sucrose.

The char water whose analysis has just been discussed consisted of 4,200 gallons off one cistern. Let us write out the analysis on sample. This adds up to 100. Let us multiply the analysis by 420. It will now add up to 42,000, which is the weight in pounds of the 4,200 gallons. Let us then reduce the water content to 20% of the total. This gives us the weight of the molasses resulting from thickening up 4,200 gallons of char water, and tells us how much water will require evaporation. Knowing the price that molasses fetches at any time and the cost of evaporation in single or multiple effect, a calculation can be made as to whether it would pay us to thicken up char water and sell the product as molasses (neglecting the serious snag of scale in the evaporators). It is possible that the evaporation could be done for nothing, if vapour from the sugar pans were used in an evaporator which was a second effect to the pans.

	Char Water Solids,	Char Water Sample.		Char Water from one cistern.	Char Water from one cistern evaporated to Molasses Brix.	Water evaporated.
Sucrose	17·9	·1755		74 lb.	74 lb.	
Invert	21·6	·2117		89	89	
Ash	33·0	·3234	× 420	136	136	
Organic	27·5	·2695		113	113	
	100·00					
Water	99·02	99·0200		41,588	103	41,485 lb.
		100·0000		42,000 lb.	515 lb.	

So that by evaporating 41,485 lb. water from 4,200 gallons of char water 515 lb. of molasses are obtained.

LOSS IN VARIOUS DRAINS.

These are difficult to account for and represent targets at which we can all shoot :—Washing sugar and syrup-drips off floors into drains instead of collecting and saving the floor water ; hosing down the yard around the raw sugar stores ; leaks ; sugar dust not being regularly sucked up by the vacuum plant, etc.

LOSS IN CONDENSER WATER.

This loss is largely a matter of plant design. Modern pans, such as those in the new Plaistow pan house are almost free from the crime of entrainment. Entrainment can be caused by drawing air into a pan or evaporator through the bottom valve, or the proof cock or proof stick. Foaming sometimes occurs in recovery pans. It sometimes occurs very suddenly, so that before it is noticed quite a large amount of foam has reached the condenser.

LOSS IN WET CHAR TO KILNS.

Any sugar not washed off the char will go to the kilns and be
burnt. There is little that we can do about this except to take every
precaution to prevent channelling in the cisterns. Once the lights
are down to a low analysis the washing is controlled only by the
way in which the ash is coming off, small traces of sugar must be
ignored.

It is no use bringing them back into the process as has been
explained in a preceding section. Patches of dusty char will not
wash off properly and will hold sweet. All we can do is to see that
the dust removal plant is working properly and that the char
cisterns are carefully settled. Sugar in char that is being burnt is
immediately noticeable by the strong smell of burning sugar at the
kilns.

LOSS IN TURNING THE SCALE BEAM.

In order to ensure that all our packages for market are of the
correct net weight, it is necessary to turn the scale beam by a small
overweight. In all our packages this averages less than 1 part in
1,000. Not bad, but not good enough. We should be able to halve
this loss. Very frequent check weighing is necessary. This we do.
What is not done as conscientiously as it could be done is to effect
an adjustment to the scale immediately it approaches the weight
limit that we work to. There is a tendency to wait and see whether
the scale will put itself right if left alone. This sometimes happens,
and it is easier to wait hopefully for this than to stop the machine
and make the adjustment. The principal cause of faulty sugar
weighing is sugar dust clinging to the scale pan. If the machine is
then set to give correct weight and some of the dust falls off, the
scale will be giving an overweight. On our bulk sugar we check
weigh every twelfth bag and and we try to turn the beam by $\frac{1}{2}$ oz.
on a 2 cwt. bag. On our small packets one girl is continuously check
weighing the output of four machines. Our weight tolerance on
2-lb. packets is -0, $+\frac{1}{2}$ dram. This gives a theoretical maximum
overweight of ·098% and an average overweight of ·049%. The
actual overweight averages about ·075%.

CHECKWEIGHING.

The question of overweight in packet sugars will be dealt with
in some detail, as an example of statistical methods of solving
problems. About 1933 we found that the checkweighing scales in
the small packet Dept. were less accurate than the Southall & Smith
automatic weighing machines that they were supposed to be
checking. We installed new checkweighing machines and introduced
statistical methods into the checkweighing.

Our 1-lb. and 2-lb. packeting machines run at 64 and 62 packets per minute. They are each fed by three automatic S. & S. weighing machines which can weigh accurately at about 23 weighings per minute. Very careful statistical investigation has proved that they are so accurate at 21 to 22 weighings per minute that they are almost as accurate as the most delicate checkweighing machine that we can buy. Clearly checkweighing is tricky.

WEEK ENDING 12·11·38   Nº 22 MACHINE   2-LB.

100 CHECKS PER WEIGHER   300 CHECKS

	$-\frac{14}{16}$ TO -1	$-\frac{11}{16}$ TO $-\frac{13}{16}$	$-\frac{8}{16}$ TO $-\frac{10}{16}$	$-\frac{5}{16}$ TO $-\frac{7}{16}$	$-\frac{2}{16}$ TO $-\frac{4}{16}$	$-\frac{1}{16}$ TO $+\frac{1}{16}$	$+\frac{2}{16}$ TO $+\frac{4}{16}$	$+\frac{5}{16}$ TO $+\frac{7}{16}$	$+\frac{8}{16}$ TO $+\frac{10}{16}$	$+\frac{11}{16}$ TO $+\frac{13}{16}$	$+\frac{14}{16}$ TO $+1$	$+1\frac{1}{16}$ TO $+1\frac{3}{16}$	$+1\frac{4}{16}$ TO $+1\frac{6}{16}$	$+1\frac{7}{16}$ TO $+1\frac{9}{16}$
WEIGHER 1			2			7	16	32	25	15	2		1	
WEIGHER 2				1	1	6	18	50	18	6				
WEIGHER 3					2	3	21	41	23	9	1			
			2	1	3	16	55	123	66	30	3		1	
%			0·7	0·3	1·0	5·3	18·3	41·0	22·0	10·0	1·0		0·3	

%
50
40
30
20
10
0

WEIGHER

$-\frac{15}{16}$ $-\frac{3}{4}$ $-\frac{9}{16}$ $-\frac{3}{8}$ $-\frac{3}{16}$ 0 $+\frac{3}{16}$ $+\frac{3}{8}$ $+\frac{9}{16}$ $+\frac{3}{4}$ $+\frac{15}{16}$ $+1\frac{1}{8}$ $+1\frac{5}{16}$ $+1\frac{1}{2}$

ERROR–DRAM
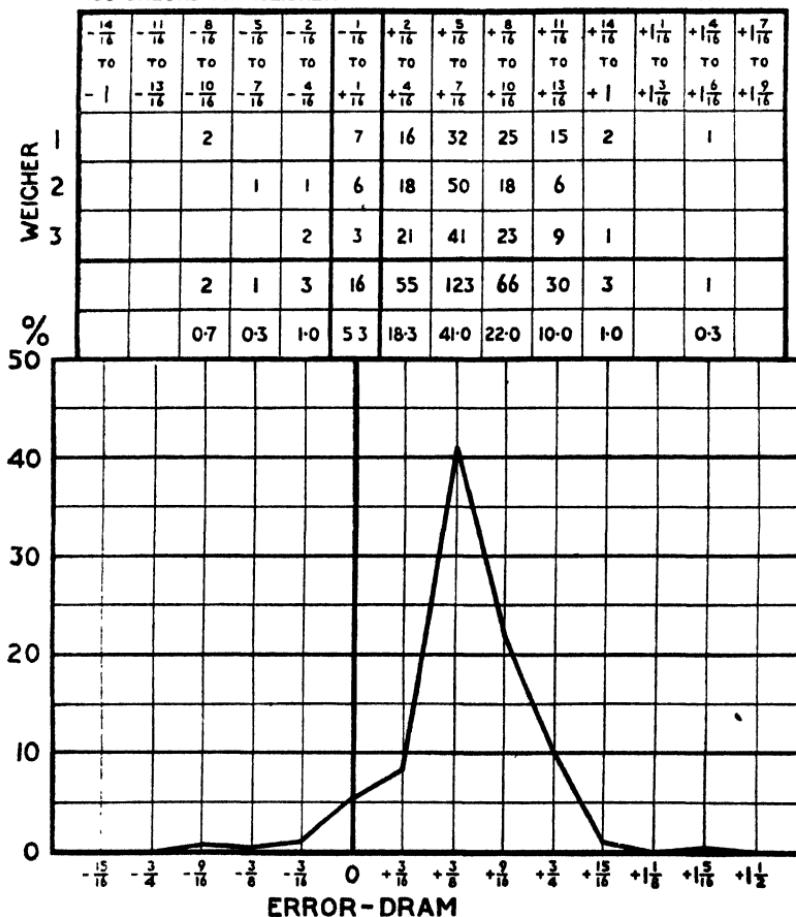
Fig. 83.
Checkweighing Frequency Curve—300 Checks.

Checkweighing is done continuously and each checkweight is noted. As soon as 100 checks have been taken from each weigher—that is 300 from each packeting machine—the checkweights are plotted on a frequency curve.

In Fig. 83 is shown a frequency curve for a 2-lb. machine, together with the statistical record from which it was drawn. The top line shows the groups into which the checkweights are classified. The next three lines show the number of weighings from each weighing machine that lie within these groups. The next line shows the total of the three weighers. The next line shows these numbers of weighings as percentages. It will be seen that the maximum overweight was one packet of $1\frac{8}{16}$ dram, or an error of 1 in 390;

		WEEK ENDING 22·7·39							12 MACHINES 2-LB.				
		100 CHECKS PER WEIGHER							3600 CHECKS				
$-\frac{14}{16}$ TO -1	$-\frac{11}{16}$ TO $-\frac{13}{16}$	$-\frac{8}{16}$ TO $-\frac{10}{16}$	$-\frac{5}{16}$ TO $-\frac{7}{16}$	$-\frac{2}{16}$ TO $-\frac{4}{16}$	$-\frac{1}{16}$ TO $+\frac{1}{16}$	$+\frac{2}{16}$ TO $+\frac{4}{16}$	$+\frac{5}{16}$ TO $+\frac{7}{16}$	$+\frac{8}{16}$ TO $+\frac{10}{16}$	$+\frac{11}{16}$ TO $+\frac{13}{16}$	$+\frac{14}{16}$ TO $+1$	$+1\frac{1}{16}$ TO $+1\frac{3}{16}$	$+1\frac{4}{16}$ TO $+1\frac{6}{16}$	$+1\frac{7}{16}$ TO $+1\frac{9}{16}$
17	14	26	22	82	190	644	960	940	444	236	5	13	9
0·5	0·4	0·7	0·6	2·3	5·3	17·9	26·7	26·1	12·3	6·5	0·1	0·4	0·2
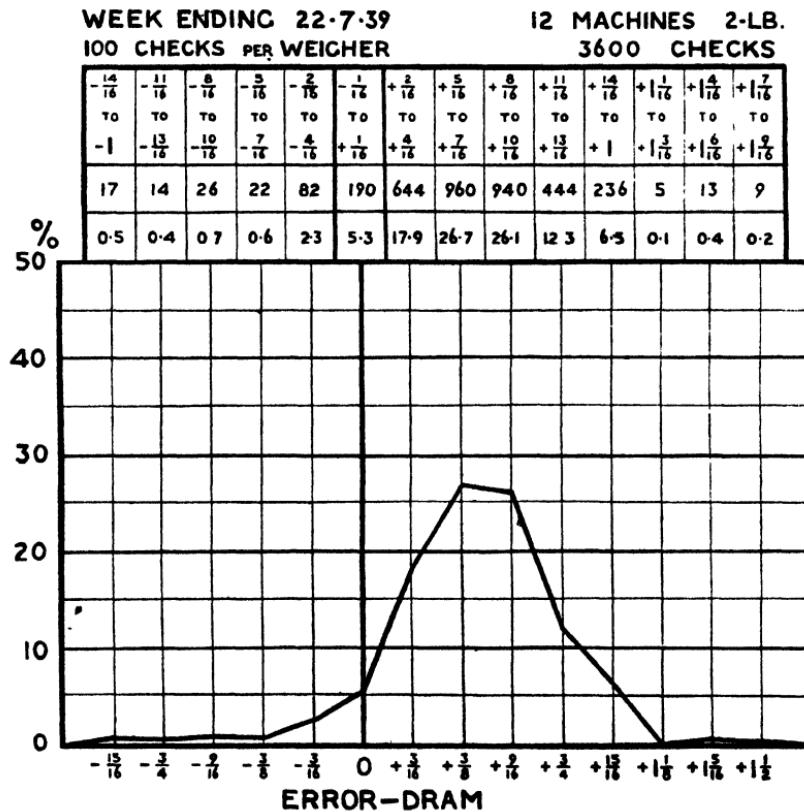
Fig. 84.
Checkweighing Frequency Curve—3,600 Checks.

that the maximum underweight was two packets of $\frac{2}{16}$ dram, or an error of 1 in 910 ; that the total number of underweight packets was 2% and that the " mode," or peak of the curve, overweight was 41% of the whole and amounted to $\frac{3}{8}$ dram or 1 in 1365.

The shape of the frequency curve is the measure of the reliability of the weighing machine (and of the checkweighing). The taller and narrower the curve, the more consistent are the weights. The position of the mode relative to the nominal weight represents the general accuracy of the weighing. The narrower the curve the nearer can the mode be brought to the nominal weight line.

The larger the number of samples weighed, the greater is the chance of widening the base of the curve. Fig. 84 is a frequency curve compiled from 100 checkweighings from each of three weighing machines feeding each of 12 2-lb. packeting machines—3,600 checkweighings. The curve is not so high or so narrow as the curve in Fig. 83, as is only to be expected ; but it is a really fine result.

If we could reduce the width of the frequency curve by 30% we could safely move the mode $\frac{2}{16}$ dram nearer the nominal weight, with a saving, at Plaistow, of 100 tons of sugar a year.

After a few weeks of this statistical analysis of checkweighing, not only was the number of light-weight packets greatly reduced, but a saving in overweight of £1,000 a year was effected.

UNKNOWN SUGAR LOSSES.

The unknown sugar loss in the statement on page 297 was just under $\frac{1}{2}$%. This may sound small, but it sounds very different if it is converted into weight. In the six months in question it amounted to 41 tons per week. It seems hardly possible that 650 lb. can be lost every working hour without our having the slightest idea as to where it is going. But it is true.

As a check on our sugar loss figures we also keep a tally of our solids loss. The solids loss agrees fairly well with the sugar loss.

LOSS DUE TO FAULTY ANALYSIS.

All our figures of losses are dependent on the accuracy of our analyses of raw sugar brought into the refinery and the refined products put out. Unless we can trust the analyses, all loss figures are meaningless. We have done all kinds of checks on our analyses, and while we find small errors these go first one way and then the other. But the loss always goes one way—loss.

There is only one analytical test which can be wrong in such a way as to affect the sugar loss and the solids loss to the same extent.

This is the estimation of water. If there is ½% more water in the raw sugar than we think there is, then we have got no unknown sugar loss. Our analyses are checked by the Sugar Association and by the Government chemist for Customs purposes. The methods of analysis used by different sugar chemists are agreed from time to time between them. If the method is wrong, these outside checks are not of real value. It is most unlikely that faulty estimation of water accounts for our unknown loss, but the fact remains that the estimation of water in raw sugars, molasses and golden syrups is one of the parts of our analysis in which we can put least faith, and is the one estimation that can put all our loss figures entirely wrong.

It is just conceivable, though extemely unlikely, that estimation of sucrose and invert in raw sugar may come out relatively higher than similar estimations in refined sugars. There is no evidence whatever that this is so. No single individual analysis is accurate to 1 in 1,000, but at Plaistow fifty raw sugar analyses are carried out every week and the averages may surely be relied on.

LOSS DUE TO CHAR ADSORPTION.

It is believed by many sugar chemists that char adsorbs sugar. This is quite possible. We have, however, never succeeded in proving any adsorption at all in the laboratory. It is very difficult to stage a full scale experiment of sufficient accuracy to be of any use. Such an experiment would necessitate the weighing of all the liquors, syrups, lights, etc., put into and taken out of at least one char cistern, as well as their analyses being carried out, all to an accuracy of 1 in 1,000. We have seen such an experiment being attemped in an American refinery, and what we saw confirms our view as to its difficulty.

If adsorption by char were the cause of unknown sugar loss, then any refinery using activated carbon should show a very small loss. The only figures available are difficult to use as a comparison.

Again, if this were the cause of the unknown loss, the loss should be directly proportional to the amount of char used. This is not the case. Liverpool use 30% more char than Thames, but Liverpool's loss, instead of being 30% greater is 30% less than the loss at Thames. The American refineries use two or three times the amount of char that we use, but their loss figures compare favourably with ours.

LOSS DUE TO DESTRUCTION ON CHAR.

It is often suggested that the unknown loss is caused by a destruction, due to fermentation or some other cause, while the sugar is passing over the char. If destruction is taking place, it can only take the form of some partial breakdown of sugar into

simpler organic bodies, or a complete breaking down into its original constituents, CO_2 and water from which it was made in the plant. If the breakdown is partial an increase in the organic should appear in the liquor off the char. If the breakdown is complete there should be a considerable evolution of the gas CO_2. There is no evidence that any increase in organic takes place, but as char adsorbs organic, it may be that organic has been made and adsorbed. If the breakdown is a fermentation into alcohol this should be detected by its smell. There is never any smell of alcohol. Whenever we have noticed gas blowing through the vents of char cisterns we have tested the gas and find that it is always air (or nitrogen—the oxygen having been adsorbed by the char), not CO_2, and is simply due to bad settling.

DESTRUCTION IN THE PANS.

It is often suggested that destruction of sugar takes place in the pans. We have not been able to prove that any destruction does take place in the pans. In the pans the liquor is for most of the time cooler than it is during filtration or in the tanks before the char, when no appreciable destruction seems to occur except for the formation of a minute weight of colouring matter. Unless there is some sinister effect upon a liquor that is actually boiling, it would seem that there can be no great loss in the pans.

If the fact of boiling was causing a destruction, then this destruction should have been greatly reduced in the Plaistow pan house where only 150% of masse is boiled instead of 220% on the old plant. The loss at Plaistow has not materially changed since the pan house was put into service. A small decrease took place, but this could well be put down to the elimination of old dirty departments.

DUST LOSS.

Whenever sugar is passed from one piece of plant to another, dust is formed by the crystals knocking little pieces off each other. The more the sugar is dropped the greater is the amount of dust formed. It is important that sugar should be conveyed from the granulators to the bagging point with the least possible number of falls. Little can be done in an old plant to remedy the tortuous path that the finished sugar must follow, but whenever an alteration is made to the handling plant an endeavour should be made to reduce the number of falls rather than to increase them.

Dust collectors are most unsatisfactory. Many kinds have been tried. That some are worse than others is about all that can be said for them. Most of our dust collectors are wet. The sugar laden air is passed through sprays of water which catch and dissolve

the sugar, the sweet water drops being trapped on baffle plates. The air leaving these collectors is always sweet, though the amount that we have been able to measure is always trifling. Occasionally a hitch occurs on the water supply, when the sugar dust will blow straight through. The resulting loss would be very serious if the collector dealing with the air from the granulators were the one affected.

Wet dust collectors produce sweet water. In addition to the sugar dust, large numbers of bacteria are washed out of the air by the water spray. Sweet water from a dust collector is always badly contaminated and liable to fermentation.

Dry dust collection is the ideal method, but it is not easy. Any form of cloth filtration is inefficient, costly in upkeep and costly in power. The best dust collector ever tried at Plaistow was an electrical plant. The dust-laden air was passed down tubes provided with central rods running down them. Tubes and rods were connected to opposite poles of a very high voltage electrical supply. This caused the dust particles to be electrically charged when they were attracted to the tubes. This machine was very efficient and removed practically the whole of the dust in a dry state. It was, however, so expensive that we were never able to decide that it was worth the money.

SUGAR LOSS DUE TO HEAT.

Invert is rapidly formed from sucrose solutions whose pH is at or below 7 if they are kept hot. Invert is destroyed by heat, particularly when the pH is high. Sugar liquors and syrups should be kept as cool as possible and should be processed as fast as possible. The ideal refinery would contain no tanks. Unfortunately, for ease of working and continuity of throughput, large tank space is needed, so that a hold-up in one department will not delay the whole process. But it is not necessary to keep tanks full. The tendency always is : " There's an empty tank. Let's fill it." The tendency seldom is : " There's a full tank. Let's empty it." If tanks must be kept full for long periods, the contents should be kept at the lowest possible temperature.

SAMPLING.

The whole of process control and loss estimation are based on analyses and tests carried out on samples. However carefully the analyses are carried out, the results are useless, in fact worse than useless—they are actively dangerous, if the sample does not truly represent the bulk of the material being considered. Generally speaking, sampling is not performed with anything like the care and accuracy that is subsequently bestowed on testing the sample. A great deal of wishful sampling occurs. If the process take the

sample, it is only human for them to try to take a good sample; this is often done quite unconsciously and with no intent to mislead. If the laboratory takes the sample there is a tendency for a poor sample to be selected in order to be sure that an unduly good one is not being taken. Whenever possible sampling should be automatic, continuous and fool-proof, and the sampling apparatus should have no lag. It is not proposed to discuss here all the possible methods of sampling or all the difficulties that surround the matter. A few points will be touched on briefly in order to indicate the sort of precautions that must be taken.

When liquids are to be sampled, a continuous drip sampler can sometimes be arranged. But a drip means a small hole that can get choked with dirt or sugar crystals. The better way is to run a small pipe to a tipping bucket or rotating disc arrangement. The small pipe can pass say 1/200th of the bulk flowing through the main pipe, and the bucket can collect say 1/25th of the quantity passed into the apparatus. This gives a sample of 1/5,000th of the bulk, and if the flow through the main pipe was continuous, the sample should be a fair average provided the bucket tips frequently. The rotating disc will draw off a much smaller fraction and is absolutely continuous, but it is a rather more elaborate device and the sample tends to lose water by evaporation. A continuous sampler that sticks or breaks down is a menace. Whatever the device used the small pipe leading to it should be very short—inches not feet, lest a lag be introduced. In the boiler house at Plaistow is an instrument which indicates and records the amount of gases dissolved in the boiler feed water. When this instrument was first installed it gave its indication two hours after the water had entered the boiler !

The sampling of solids is generally more difficult than the sampling of liquids. Anyone who is interested should find out just how the sample of coal is taken in order that the little pinch of coal dust used to find its heating power is representative of the 200 tons burnt during the day. It is on this pinch that the whole of the efficiency figures of the boiler house are based.

Although granulated sugar would seem to be a homogeneous granular material easy to sample, this is not the case. Where is the sample to be drawn ? The three boilings are mixed together on the band carrying the sugar from the granulators to the filling point. If the sample is taken too early there is a big risk that the boilings are not intimately mixed and one of two things can result. Either a poor quality may be sent to market or a lot of wasteful evaporation may be done by using too much wash water. The sample should not be taken until it is certain that the three boilings are intimately mixed. It has been pointed out in Chapter 10 that

rolled grain .contains more impurities than even crystals. Rolled grain is usually present in comparatively large lumps which, being more nearly round in shape than crystals, tend to roll furthest whenever the sugar is dropped. Any sampling arrangement must be such that it collects a fair share of all the different sizes of grain. The filling point is surely the best place to take the sample. Yes, but we have over thirty filling points, and the samples taken from each are not the same. For example the distributing conveyor on the west side of the small packet department at Plaistow is such that the middle machines get the smaller grain and the big grain, including the rolled lumps, if any, go into the end machines. The east side conveyor system has been designed to eliminate this fault, and an east side packet is pretty well representative of the output, whereas every machine on the west side will give a different result.

One of the most difficult things to sample is a full tank. If the tank is used, as in the recovery house, for liquids whose analysis changes frequently and appreciably, there may be layers of quite different materials at different depths in the tank. A sample dipped from the top, or one run from the bottom may not be at all representative of the average composition. Samples must either be drawn from all parts of the tank or the sample must be estimated from samples continuously drawn from the liquid flowing into the tank taken over a time corresponding to the amount of liquid in the tank and the rate of flow through it. When the analysis of a tank is of very great importance, for example, output molasses for Government analysis, the sample is taken by lowering a tube into the tank. This tube contains a close-fitting tube inside it. In both tubes are cut a row of slots, which extend along their full length. By turning the inner tube, these slots can be brought together so that the slots are open to the outside, or the inner tube can be turned so that the slots do not coincide. The slots act as a valve the full length of the tubes. When the tube is put into the tank the inner tube is turned into such a position that the slots are shut. When the tube has reached the bottom of the tank the inner tube is turned and the slots open. Part of every layer of liquid in the tank runs into the tube which then contains a true average sample of that part of the tank. If the tank is long, a tube sample is taken from several separate places, and the various samples mixed together.

We will digress for a moment from strict sampling and consider something similar. The dipping of a tank containing a foamy syrup, in order to find the contents of the tank, presents great difficulty. We get over this difficulty by lowering a glass tube fitted with a valve at its foot into the tank. When the foot of the tube has reached the bottom of the tank, the tube is filled with water and the foot valve is opened. The water runs out of the tube until

the column of water in the tube is balanced by the column of foamy syrup in the tank. From the height of the water column and the Brix of the syrup—taken by refractometer—we can easily and accurately calculate the weight of syrup and foam in the tank. This is the method used by us and the Customs for measuring the quantity of our output molasses. Our molasses reservoirs have such glass tubes permanently fixed to them.

The sampling of press cake is very difficult to carry out correctly. A large number of random samples must be taken and mixed up together. Press cake that has been imperfectly washed off is distinguishable from well-washed cake by a different colour. Unless some means can be devised whereby the cake cannot be seen during sampling or the whole cake is perfectly mixed before the sample is taken, the accuracy of the sample should be doubted.

Sampling is full of pitfalls. Samples being carried from the sampling point to the laboratory must be tightly covered. It is not the slightest use drawing a sample of, say, boiler feed water in order to do an alpha-naphthol sweet test and carrying it in an open bottle through the granulator floor and stopping for a chat with the granulator man about the result of the 2.30 !

Every sampling method or device should be continually questioned and criticised. An intelligently taken spot sample is often much more valuable than an average continuous sample unless the continuous sampler is above reproach in every way.

Pages might be written on sampling. It is hoped that this short section, which shows some of the difficulties, will make everyone whose duty it is to take samples, realise that unless a sample really represents the bulk material, the error may be exactly the same as guessing the weight of a material instead of weighing it.

HEAT LOSS.

Heat is lost chiefly up the boiler chimney. Boiler efficiency and chimney loss have been discussed in Chapter 6. Another great heat loss is by radiation and convection. Lagging and aluminium paint have been discussed in Chapter 5. Broken windows, open doors, tanks left full unnecessarily, liquors raised to too high a temperature ; all these are simple losses that everyone can help to reduce.

It is difficult to say where heat loss finishes and where heat saving begins.

HEAT SAVING.

The best way to show how heat can be saved is to mention

some actual heat savings that have been carried out during the last few years. The principal ways in which heat can be saved in a refinery are by reducing evaporation to an absolute minimum and by the use of waste heat wherever possible.

Here is a statement of the coal used at Plaistow during six consecutive half-years :—

Period.	Av. Weekly Melt. Tons.	% Coal on Melt. Boilers and Kilns.	% Coal on Melt converted to constant heating power of 7,000 C.H.U. per lb.
Summer, 1937	8,010	22·4	23·1
Winter, 37/38	7,830	22·6	23·2
Summer, 1938	7,977	20·0	19·8
Winter, 38/39	7,096	17·8	17·4
Summer, 1939	8,575	15·2	15·3
Winter, 39/40	6,087	13·4	13·1

This is a remarkable record. It was the result of a heat campaign which has as its goal the reduction of coal consumption to below the 10% figure, which, had it not been for the war, might well have already been achieved. The coal consumption has been reduced by 10% on melt. The most important economies that have produced this result are as follow :—

Item.	Coal saved % Melt.
(*a*) New high pressure boilers	3·3
(*b*) High yield granulated boilings . . .	2·3
(*c*) High performance fine sugar machines . .	·5
(*d*) Accurate automatic reduction of granulated syrups	·35
(*e*) Use of heavy lights to reduce supersaturation of granulated syrups	·23
(*f*) Turbine gland leaks and distilled water flash piped to low press main . . .	·5
(*g*) Collection and use of blow-down flash, etc. .	·35
(*h*) Surface condenser water for granulator air heating	·25
(*i*) Rearrangement of steam mains and accumulator to eliminate safety-valve blows	
(*j*) Char lights battery	
(*k*) Char water battery	2·22
(*l*) Reduction in radiation by better lagging and shorter steam pipes	

<div align="right">

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10·00

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All these savings could be accurately measured with the excep-

tion of items (*i*), (*j*), (*k*) and (*l*). The total shown against them is the unaccounted-for saving.

Items (*g*) and (*h*) are the only items that may not be clear without explanation, and they will now be described as examples of heat-saving methods. Raw town water comes into the factory and is used as a make-up for char washing, and (after distillation) as boiler feed. All this water passes through the surface condensers attached to the fine sugar pans, whereby it is heated up to 55° C. It then went to the water softening plant where it was heated up to 80° C. by live steam, and then used as feed for the still. A small portion went for char washing to the Hawley boilers where it was heated up to 100° C. The saving (*h*) was obtained by passing part of the water from the surface condensers through the heating coils of the granulator air-conditioning plant and pumping it back to the surface condensers.

Saving (*g*) was obtained by passing the water from the surface condensers through a piece of plant called the " centipede " on its way to the softening plant. The centipede is a long jet condenser provided with many steam inlets. Steam at atmospheric pressure from blow-down flash, ejector exhausts, etc., that had previously been wasted, was piped into the centipede where it heated all the water from 55° C. to about 65° C.

A considerable future saving is in course of completion on the lines of (*h*). All the factory heating, offices, stores, canteens, packing departments, laboratories, etc., will shortly be heated by surface condenser water, thereby getting all factory heating for nothing.

Another future saving is also in course of completion by modifying item (*g*). The town water that is drawn off the factory-heating-surface-condenser system for boiler feed will go through the surface condenser of the brown liquor evaporator, where it will be heated from 55° C. to about 70° C. It will then go through the centipede where it will be heated to 80° C., and no steam will be needed in the water treatment plant. The steam that would have been used in the water treatment plant will be put into the brown liquor evaporator, where it will raise all the brown liquor by 2° to 3° Brix. The town water will be heated to exactly the same temperature as before and we shall get a minimum of 2° Brix for nothing. The brown liquor evaporator is simply the cooler-evaporator—see page 253—with a surface condenser instead of a jet condenser and a calandria added to take the steam. It will continue to function as a flash evaporator just as hitherto, and as a steam-heated evaporator as well.

POWER SAVING—THE STEAM/POWER RATIO.

The actual money saved by an economy in power is relatively

small. One hundred horse-power costs us less than £10 a week. But power saving may be much more important than just the saving in the cost of the power.

In a sugar refinery steam is generated in the boilers for the prime purpose of boiling the sugar and for other process purposes. It is generated at such a pressure that it can make sufficient electricity for the needs of the factory by expanding from boiler pressure down to process pressure in the turbine. The process demands for steam vary quite considerably, whereas the electrical load is fairly constant. Obviously the electrical load must be capable of being dealt with by the smallest amount of steam that the process ever uses. If the turbine takes more steam than the process can use the turbine exhaust will have to blow off through the process-main safety valves. This would be very wasteful.

Whenever a process improvement is made, it generally means a saving in steam accompanied by an increase in power. Whenever a labour-saving improvement is made it is almost always accompanied by an increase in power demand. In 1934 the position at Plaistow had become acute. The demand for steam was so much reduced and the demand for power so much increased that the 45-lb. process main was frequently blowing off, because the turbine needed more steam than the process could use. Steam saving became impossible. It was therefore decided to instal new boilers of much higher pressure so that electricity could be generated with a much smaller steam consumption. The new turbines, taking steam at 650 lb. and exhausting at 70 lb., only use 29 lb. of steam per K.W.H. The old turbine, taking steam at 250 lb. and exhausting at 45 lb., used 50 lb. steam per K.W.H. In this way it was thought that an ample margin of power over steam consumption would be obtained, as well as an ample supply of steam through the still for making boiler feed.

At the same time, the new pan house was built. The steam economies resulting from the new plant and from the other improvements already mentioned in this chapter were so greatly beyond expectation that in 1939 we were back again in the position of passing too much steam through the turbine and too little through the still. It was therefore necessary to tackle the problem from the other end—namely power-saving. Plaistow is very fortunately situated in having four frequencies : 50 cycles from the turbine, 25 cycles from the big reversible motor generators put in to effect the change-over from 25 to 50 cycles, 42·8 cycles for the fine sugar centrifugal machines, supplied by a frequency changer of large capacity, 57 cycles for the recovery centrifugal machines. Induction motors will run on these frequencies at the following approximate speeds :—

No. of Poles.	500 Volts. 57 Cycle.	440 Volts. 50 Cycle.	375 Volts. 42·8 Cycle.	220 Volts. 25 Cycle.
2	3,250	2,850	2,440	1,425
4	1,620	1,425	1,220	715
6	1,080	950	815	475
8	815	715	610	357
10	650	570	490	285
12	540	475	407	238

We set about finding how slow we could run our plant. We found that almost all our vacuum pumps could run at half speed and still give an adequate vacuum ; the only disadvantage being that it takes about five minutes longer to lift the pan vacuum from atmospheric pressure. The vacuum pumps were therefore put on to the 25-cycle supply. We found that the granulator air fans, both forced and induced, as well as all the air-conditioning fans could suffer a 15% speed reduction and still do their stuff. So they went on to the 42·8-cycle supply. The same applied to the biggest motors of all, the river-water pumps. We found that the boiler feed pumps delivered at an excessive margin of pressure over boiler pressure. We took one stage out of the boiler feed pumps, leaving five stages instead of six. And so on and so on ; using a few bits of cable and changing a motor here and there, we reduced the electrical load by over 700 K.W. The reason for setting this all down here is to show by practical example how savings can be effected and how effective simple remedies can sometimes be.

WASTE OF PACKING MATERIALS.

Every year T. & L. use packing materials to the value of some £1,250,000. A 1% waste of packing material costs £12,500 a year, and 1% waste all round is not too bad a figure. The biggest potential wasters are the small packet machines. Many packeting machines run with a waste below 1%—sometimes as low as ·2% for a few days—but often they have bad days when the waste exceeds 3%. The waste of each machine is worked out every day, but these figures seldom add up to the real waste which can only be obtained by subtracting the output from the material taken into the department. It is a difficult matter to decide when a machine is wasting sufficient to warrant its being shut down for adjustment. Often the waste is not due to faulty adjustment of the machine, but is due to humid atmosphere or damp cardboard. An idle machine with an idle crew costs about 5s. an hour, without counting the loss of output, or loss of potential profit or any overhead charges. On the other hand, two and a half minutes work all wasted also costs 5s. When a machine is wasting 4% to 5% it pays to shut it down rather than run it. Cleanliness of the machines and of the whole department is one of the best insurances against waste.

Of all packing material used, tinplate is the most valuable. The waste in filling the finished cans is quite negligible. The big possible source of tinplate waste is in the can-making department. One per cent. waste of tinplate represents a loss of £3 to £4 a day. We seldom have a waste of less than 1%. This is a high figure compared to, say, an open-top can factory. We make what we believe is the best can in the world. Our standard is much higher than that of any can factory we have ever visited, and, due to the quality that we strive for, we cannot use the standard can-making machines. The machines we use are very temperamental, and a 90% output with ·8% waste is, we consider, a really good day's work.

BREAKDOWNS.

Breakdowns in a process factory are not entirely mechanical. The term must include such disasters as the jamming of a gear due to wrong consistency of the material being dealt with, or to the blocking of a pipe with sugar grain, or to the overfilling of a tank with consequent floor mess, or to bacterial infection of some part of the process.

Only in very exceptional cases are breakdowns purely accidental and unavoidable. The ordinary run of breakdowns are due to two main causes.

1. Inadequate precautionary maintenance.

2. Ill-treatment of plant, in which is included simple careless-ness, and incorrect process work.

Regular inspection of plant, not only by the maintenance staff but by the users, should in most cases detect signs of wear and coming breakdown. Where inspection is impossible, a regular routine of overhaul should be laid down and strictly adhered to.

Plant ill-treatment is a difficult matter. A mixer or conveyor jams. It is very tempting to try to get it going again by means of its own motor. In nine cases out of ten this comes off all right. In the tenth case the shaft fractures or the gear breaks. Experience is really the only quality that enables a correct decision to be made, but experience is of little value if it is coupled with impetuosity. The real cure is correct process work. If the materials being handled are always kept at the right consistency the gear will not jam. If a chain of plant is to be started the furthest link in the chain must always be started first so as to ensure that material is not put into stationary plant. Syrups that are over saturation will throw down grain. This must always be remembered and pipe-blockages guarded against by regular removal of the grain. If centrifugal machines are never allowed to run for too long, the sugar in the

machines will never set hard and cause the ploughs to tear the machine cloths. (A machine cloth costs £4 5s., and one is torn every two weeks at Plaistow. Most of these tears are primarily due to careless cloth fitting.)

The regular inspection of switch contacts is of the utmost importance. By more rigorous contact inspection we have almost eliminated one of the most frequent causes of electrical breakdown in the past—the running of motors on two phases. The more general use of contactors on even the smallest motors has greatly minimised breakdown, though it has increased minor maintenance. The contactor makes and breaks with a punch that hand operation cannot equal, but it is an additional mechanism that needs looking after.

Messes due to tank overflows are minimised nowadays by more reliable tank contents indicators, but overflows are bound to occur at times. The provision of pipe overflows is, generally speaking, undesirable on anything except water. They make for carelessness and inattention, and liquor may be left circulating for long periods unnecessarily with increase in colour formation. Every time a sugar liquor is pumped its colour is increased.

There are two schools of thought regarding messes. The old-fashioned view was to make the floor tight and then it does not matter if the tank does come over. In fact the floor was often used as a tank in the " good " old days. This is a demoralising and unclean point of view. The other school says, make a minimum of floor and the tank must just not come over. This attitude is stimulating and makes for cleanliness and attention. A compromise is probably necessary.

The top 112 feet of the Plaistow pan house is open, and there is no tight floor until the sub-machine floor. This protects the granulator floor, where the sugar first appears dry, from drips. The granulator floor is tight, which prevents the escape of sugar dust and enables the granulator floor to be kept under pressure, so preventing the ingress of dust and thermophils.

A recovery house should probably have as many tight floors as possible. This is the design adopted for the new recovery house at Liverpool. Recovery products are so messy that any tank overflow should be caught as soon as possible. Recovery products are sometimes subject to rapid and uncontrollable foaming, and messes are much more frequent than in a fine sugar house.

Smooth and correct process work goes a long way towards the elimination of process and mechanical breakdowns. A breakdown such as to hold up the whole process, costs, at Plaistow, about one shilling a second.

LABOUR SAVING.

Labour saving does not necessarily mean labour dismissals. In the long run it almost certainly means the contrary. In the last ten years at Plaistow, labour savings have been made amounting to over 150 men and 100 girls, but the numbers employed show thus :

	Men.	Girls.
1930 . . .	1,631	870
1940 . . .	1,639	967

The labour that was saved during the ten years, but that has not apparently been dismissed, was saved by the following economies, amongst many other minor savings :—

Item.	Labour saved.
New bulk filling point	12 men
Wind tunnel in place of riddles . . .	4 ,,
F.O.B. conveyor	12 ,,
Fiberites instead of wooden cases . .	26 ,,
High speed second and third crop machines .	12 ,,
Rearrangement of mud presses . . .	6 ,,
Bulk acid handling	3 ,,
New pan house	30 ,,
New boiler house	24 ,,
Rearrangement of can-making dept. . .	70 girls

A successful business cannot stand still. It must progress. If it tries to stay still it will stagnate and decline. A concern that makes savings, avoids losses and improves the quality of its products can take on new enterprises, or put new and better products on the market, or give its customers better services, or cheapen its products, and possibly increase its output.

Every man saved makes the jobs of those remaining more secure and there is a good chance that the " saved " man will either not be dismissed or will soon be re-engaged for some other enterprise. A man is very naturally afraid of being displaced by a machine, but it is only by the installation of economical machinery that employment is available in such large and varied amount.

Some years ago one of T. & L.'s directors was walking down the Edgware Road and stopped, at a new bridge that was being built, to watch three riveters working a pneumatic hammer. An unemployed man came up to him and said, " If it wasn't for that bloody thing there would be ten men working there instead of three." J. J. R. replied, " If it wasn't for that bloody thing there would be no bridge being built and those three men might be looking for jobs."

QUALITY CONTROL.

The control of the process is in the hands of the shift manager. The essence of control consists in producing the maximum quantity (unless output restriction is necessary) of finished sugar of a quality above certain rigid limits with the maximum of economy. At Plaistow only one sugar quality is made and the quality limits in 1939 were :—

				Limits.	Actual Average Output.
Colour	.	.	.	12	11
Invert	.	.	.	0·01%	0·008%
Ash	.	.	.	0·009%	0·006%

T. & L. work on impurity control. Apart from the Colonial Sugar Refining Company the writer knows of no other sugar concern that employs impurity control. The sugar world as a whole uses purity control. " Purity " means the sucrose on solids. In practice not even the purity is used but the " apparent purity " or Pol on solids. The apparent purity is the same as the true purity when there is no invert sugar present, but it is a meaningless measure when there are varying amounts of invert in the materials. Impurity tests are just as easy and quick to carry out ; in fact ash can be determined quicker than polarisation, and if the true purity is to be found it is necessary to measure the invert anyhow.

Here is an analysis of a fine liquor. The apparent purity is also shown within limits of accuracy of $0·1\%$ either way (the polarisation for process control purposes is unlikely to be more accurate than this). The total amount of impurities in this liquor from the analysis is ·36%. The impurities shown by the apparent purity lie between ·28 and ·48%. This shows that by measuring the purity, the impurities cannot be estimated within 25%. By measuring the impurities direct they can be ascertained within an accuracy of 5% and the tests are easier and quicker than purity tests.

						Fine Liquor.
Sucrose .	.	.	.	.	.	99·64
Invert .	.	.	.	.	.	·07
Ash	.	.	.	.	.	·12
Organic	.	.	.	.	.	·17
Apparent purity	.	.	.	.	.	99·52 to 99·72

The shift manager has constant help and advice from the laboratory. The laboratory at Plaistow carries out some 1,500 tests each day for the guidance of the shift manager, for record, and for purchase and duty purposes. The shift manager must decide, when the laboratory inform him that a quality limit is being approached, the best way of dealing with the problem. This can probably be tackled in two or three different parts of the process.

If the granulated sugar colour is approaching 12 there are three possible principal remedies.

> A shortening of the liquor char starts.
> An increase in affination wash.
> An increase in fine sugar wash.

Of all these, shortening the starts is probably the cheapest, but it is slow to take effect ; probably the full effect will not be noticed for twenty-four hours.

Improvement in affination depends on the state of the recovery house. If West Indian is being melted the recovery house is probably the process bottle-neck, so that the affination wash cannot be increased without overloading the recovery house. If Australian or Natal is being melted the recovery house will be lightly loaded and the affination wash can be increased if it is not already up to its economic limit. Improved affination will produce no effect on the white sugar for eight or twelve hours.

An increase of fine sugar wash gives instant results and may have to be done while waiting for one of the other remedies to take effect. But it may not be possible without reducing the melt. If Australian or Natal is being melted the filtration will be bad and the brown liquor Brix will be low. This may mean that the fine sugar pans are the bottle-neck owing to the extra evaporation that they must do. An increase of fine sugar wash will overload the second and third boiling pans. If Java, Mauritius or Beet sugars are being melted the filtration will be good and the Brix high. The fine pans will probably be able to do a little more work so that the fine wash can be increased. If it is decided to increase the fine sugar wash a decision must be made as to which boiling is to receive the extra water. If the third boiling is poor in quality an increase in third boiling wash only may be all that is required. Seven pounds of water on the third boiling is the equivalent in evaporation of 1 lb. of water on the first boiling, because the third boiling is only one-seventh of the first in quantity.

If the invert in the fine sugar approaches 0.01% there is probably little use in interfering with the char starts. Reduction in the start will probably have no effect on the invert. The better way will be to improve the affination or if this cannot be done the fine wash will have to be increased.

If the fine sugar ash approaches 0.009% it will probably have to be put right by shortening the char starts. Washing, either in the affination or in the fine machines has not got such an effect on ash as on colour or invert because the sugar crystals adsorb ash on their surfaces. Another remedy, if filtration will permit, is to lower the pH of the carbonatation.

The performance of centrifugal machines has a curious effect on sugar quality. In the old Plaistow plant and at present in Thames and Liverpool, where the fine machines run at 750 r.p.m. the fine sugar is washed for colour 90% of the time. In the Plaistow pan house, where the fine machines run at 1,200 r.p.m. and the centrifugal effect is twice as great, the wash is for ash 90% of the time.

There are a multitude of other points that require quality control, but the example given above is sufficient to give an insight into the problem. No hard and fast rules can be laid down where the raw material is constantly changing in qualities every few days. Sometimes we get a run of a few weeks on practically constant raw sugar, when everything runs smoothly and easily.

MELT CONTROL.

Most sugar refineries in the world refine fairly constant raw sugars. We refine all kinds and seldom run for more than a few weeks on any one kind. Often we change from, say, West Indian to Australian once or twice a week. Here are some analyses of raw sugars that we are regularly melting.

	SAMPLE.					SOLIDS.			
	Sucrose.	Invert.	Ash.	Organic.	Water.	Sucrose.	Invert.	Ash.	Organic.
Cuba . .	96·92	·87	·55	·82	·84	97·73	·88	·56	·83
West India .	95·34	1·68	·80	1·04	1·14	96·44	1·70	·81	1·05
San Domingo .	97·13	1·03	·45	·72	·67	97·78	1·04	·45	·73
Australia .	98·75	·30	·23	·33	·39	99·14	·30	·23	·33
Natal . .	97·92	·64	·38	·42	·64	98·56	·64	·38	·42
Java . .	97·48	·92	·49	·45	·66	98·13	·93	·49	·45
Mauritius .	98·74	·23	·26	·49	·28	99·02	·23	·26	·49
British Beet .	97·98	Tr	·40	·71	·91	98·88	Tr	·40	·72

Cuban sugar contains a fair amount of impurities, but they are removed without great difficulty. When we are melting Cuban sugar all parts of our process are approximately evenly loaded. It is on a melt of Cuban sugar that we measure our capacity which in 1939 was :—

Liverpool . . . . 13,000 tons per week
Thames . . . . 12,500 ,, ,, ,,
Plaistow . . . . 8,500 ,, ,, ,,

West Indian sugar contains a lot of invert and non-sugars. The recovery house becomes the bottle-neck, but the overloading of the recovery house is not as great as the analysis would indicate because the affination of West Indian usually requires less wash

water than Cuban sugar.   West Indian usually filters better than Cuban.

San Domingo, like Cuban, loads the process evenly, but is in every way rather easier to work than Cuban.   It filters more easily but the liquor is usually rather high in ash.

Australian and Natal have a low percentage of non-sugars, so that the recovery house is lightly loaded when these raws are being melted.   However, they do not wash up well and the liquor from them filters with great difficulty.   Of all the sugars we get, they are the most difficult to filter.

Mauritius and British beet are easy to work.   They wash up well.   The recovery house is lightly loaded and filtration is easy. The Brix of the brown liquor is limited by the speed at which it will run over the char—about 71° Brix.

It is hardly ever possible for the refinery to choose, except within very narrow limits, what sugar to melt.   Sugar is bought from different parts of the world according to price and season. It is impossible to arrange that a cargo of Natal will coincide with a cargo of Mauritius.   If there is sugar in the river it must be melted. If sugar is left in the river, three extra charges are incurred.   Demurrage on the craft in river and piling and unpiling costs in raw sugar store.   These charges will almost always be more than the saving effected by selective melting.   All that we can and do do is to try to keep a silo full of Mauritius or Beet to help things out a bit when Natal or Australian are being particularly troublesome.

The rate of melting is controlled by the sales position and the stock in warehouse.   An endeavour is made to run for the whole week at a constant melt.   When the rate of melt is decided upon, the rates of the chars are set to give the required throughput.   The starts are lengthened until the quality limit is approached.   The Brix of the brown liquor is raised until the filters will just pass the melt and no more.   The affination machines are put on to the longest spin that will wash the melt.

When the refinery is to do the maximum possible melt the control point generally shifts out of the char house.   The Brix of the brown liquor is lowered to assist filtration until the fine sugar pans become the bottle-neck.   The moment filtration improves the Brix is raised.   This is the usual method of working fully. Occasionally the affination becomes the bottle-neck if the recovery house is fully loaded.   It should be the aim of the management to have every part of the process fully loaded when the refinery is on full melt.

REFINING EFFICIENCY OF VARIOUS PROCESSES.

Our present processes are not necessarily the best refining processes. We could do as we did before the introduction of affination and so eliminate the recovery house ; melt everything and put the bad brown liquor over char. Or we could boil a new raw sugar from the melted raw. Or we could dispense with char, by boiling and melting and boiling and melting until we had, by crystallisation, separated all the impurities into the syrups and the final sugar was pure enough for market. We have reached the present arrangement of processes by many years of groping and experiment. Most of the refineries in the world are working on similar lines. Here is a list of our processes with their efficiency as non-sugar and colour removers :—

PROCESS.	NON-SUGAR In.	Out.	COLOUR. In.	Out.	COST : Pence per cwt. melt.
Affination	100	21	100	25	·64
(Recovery)					1·47
Carbonatation	100	96	100	60	·96
Char	100	67	100	2	1·46
Crystallisation	100	10	100	9	3·30

The cost for recovery must be added to the affination costs because recovery is caused by affination. The last cost of crystallisation is too high for correct comparison, because in our process costing system the crystallisation process is costed from the fine liquor tanks to the filling point. Many costs that would anyhow have to be incurred are therefore included. (Granulation and riddling for example.)

These figures are interesting, but too much must not be read into them. Carbonatation looks bad, but some form of filtration is necessary if only to remove bacteria, and kieselguhr filtration would look even worse in a similar comparison.

FIGURES AND STATISTICS.

A large number of figures are worked out weekly.

On Monday midday the approximate sugar loss for the previous week is known. This is an unreliable figure when any one week is looked at alone, owing to the difficulty of taking stock of sugar in partly filled silos. Loss figures must be estimated over a number of weeks. On Tuesday night the profits for the previous week are known to an accuracy of about 3%. On Thursday the working expenses for the previous week are known to an accuracy of about 1%. Each week the figures are cumulated and increase in accuracy until at the half yearly balance they correspond almost exactly with the auditor's figures. In this way alterations in raw

sugar, refined output, waste, savings, process changes, etc., can be related to their effect on costs in a way that would be totally impossible were we to wait till the end of an accounting period, when the results would merely be the combined effect of many factors.

In addition, in London, there is a complete system of process costing which is still experimental, but is giving a lot of most valuable information.

Apart from financial figures, weekly averages are made of all analyses and process figures, as well as those of boiler house performance, etc.

While without such figures no control or direction of the business would be possible, there is a danger in taking out too many figures. If the figures produced for the management to examine are too great in scope and detail, there is a very real danger that they will not be looked at. The statistics should all be kept and filed away for use when needed, but management must resist being swamped by routine detail. A manager or foreman should try never to get his work into such a state that he " has not got time." If he can dispose of his routine detail in a short time he will always be able to carry out the detailed economy or efficiency crusades which form such an essential part in keeping a factory, and particularly a process factory, up to the mark.

CHAPTER 16. COMMERCIAL.

You do not often get the chance
Of seeing sugar brokers dance
From their abode
In Fulham Road
Through Brompton to the City.

GILBERT—Bab Ballads—1890 ?

Brief History of Sugar Refining—Reasons for a Sugar Refining Industry—Raw Sugar Purchase—The Sugar Association—The Sugar Duty in the Past—" In Bond," " Out of Bond "—The 1901 Duty Scale—Operations under the 1901 Scale—Protection—Empire Preference—Drawback—Excise Duty—Payment of Duty—Advantages and Disadvantages of the Sugar Duty—Story of a Typical Raw Sugar Transaction—The Distributive Trade—The Wholesaler—Distribution—Story of a Typical Refined Sugar Transaction—Finance—Balance Sheet—Brief History of Tate & Lyle Ltd.

BRIEF HISTORY OF SUGAR REFINING.

The Sugar Cane has been known and used by mankind for nearly 3,000 years. Some 300 years B.C. soldiers of Alexander the Great were the first Europeans to see the sugar cane, which grew wild in India and China. Pliny, in A.D. 74, describes sugar produced from the cane as being " white and brittle," which indicates that some sort of refining must have been going on. About A.D. 600 the boiling of cane juice to assist crystallisation was practised. The first record of any refining process seems to be by Marco Polo, the great mediæval traveller and adventurer, who states that about A.D. 1300 Egyptians had introduced into China from Egypt a process of refining by means of ashes. In 1264 the King of England had sugar in his household. There is a record in 1319 of the importation of a cargo of sugar to London at a price of 1s. 9½d. per pound. There is no record of any separate refineries during these times, except at Venice, where sugar refining was a close secret for centuries. Between A.D. 1500 and 1600 refineries were built in many of the consuming countries, as the Venetians had revealed their secrets.

Sugar refining was first started in England in 1544. In spite of many financial ups and downs the industry expanded rapidly, and in the next 100 years more than fifty refineries were built. In the

following 100 years the number had risen to 120. They were small family affairs. Between them, in the year 1750, they refined 30,000 tons, or an average weekly melt of 5 tons each. The average number of employees was about fifteen in each, including members of the refiner's family. In 1780 the melt of the two leading London refineries was 16 hogsheads, or 13 tons, per week. The raw sugar cost 34s. per cwt. and the refined loaf sugar sold for 62s. Such was the cost of the process that these prices showed the refiners a loss.

At this time there were eighty-seven refiners in London. They were in a bad way. Prices fluctuated violently. Wars and political wrangles upset the industry. The whole history of refining from 1700 to 1800 is a series of political difficulties. Each section of the sugar industry urged on the Government preferential treatment against the other. The West Indian producers and the home refiners were waging constant battle.

The beet industry was soon to introduce another party into the quarrel. In 1747 Margraff isolated sucrose from the beetroot. In 1802 Achard manufactured beet sugar at Cunern in Silesia.

The first twenty years of the nineteenth century saw the dawn of modern refining. James Watt had made the steam engine a practical tool. Figuier had prepared bone charcoal, which had been put to practical test at Orleans. Howard had invented the vacuum pan. The stage was set.

Granulated sugar was not produced in any quantity until the suspended centrifugal machine became practical. Until the middle of the nineteenth century refined sugar was all made into loaves. The raw sugar was melted and a bucket of bullock's blood was put into the blow-up. The blood coagulated in the hot liquor and collected much of the impurities into a scum which could be skimmed off. The liquor was then filtered through a woollen cloth. The massecuite was taken from the pans, which until about 1820 were all coal fired, and poured into cone-shaped moulds. When these had cooled and set sufficiently to stand handling, the loaves of sugar were taken out and allowed to stand so that the syrup could drain out of them. A fine syrup was poured over them a number of times until they were washed white. They were then allowed to stand so that the syrup partially dried and by crystallising out cemented the original grains together. The loaves were then stoved to dry and harden them. The whole process took about a month.

In 1837 Penzoldt invented the centrifugal machine, which revolutionised the whole sugar industry, although Penzoldt had invented the machine for drying wool. Raw sugar had hitherto been made by allowing the massecuite to cool and crystallise into a very heavy masse which was put into loosely put together hogs-

heads, which were allowed to stand. The syrup drained out of the loosely secured staves and when no more syrup flowed the hoops were driven and the barrel was ready for shipment. The bottom or foot of the hogshead was wet and syrupy and was often separated and sold as " foots " sugar.

The first centrifugals were underdriven, and the sugar had to be dug out of them. In 1852 Sir Henry Bessemer, of steel fame, invented the suspended centrifugal machine. This was not a mechanical success until 1867, when Weston made the machine workable. (Bessemer built a large refinery on the Thames to work a new process of his own invention. The process was a failure and the refinery had to be shut down.)

The suspended centrifugal machine enabled granulated sugar of high quality to be made easily and cheaply, so that it quickly became a serious competitor of loaf sugar. A number of processes were soon invented for making sugar into slabs which could be cut into cubes, when the process made its product in days instead of weeks taken in the loaf process. The Langen was the first of these processes, but had to give way before the better processes invented by Adant and Hübner. The Adant process produces the best cube, but requires an immense expensive plant. The Hübner uses a comparatively small plant, but the resulting cube is not quite so hard, sparkling or white as the Adant product. We use the Adant process at Thames and the Hübner process in Liverpool. (See Chapter 17., pages 365 & 367.)

The introduction of the steam engine, the steam-heated vacuum pan, the bone charcoal process and the centrifugal machine so improved and cheapened sugar refining that any concern who could afford to instal this plant quickly put its competitors out of business. The result was a great increase in sugar refining but a great decrease in the number of refineries. In 1900 there were only thirteen refineries in Great Britain. That nothing succeeds like success is still the case. The surviving successful refineries are turning out (in 1939) nearly three times the refined sugar that was produced in 1900, but this quantity is handled by only eight refineries.

The last half of the nineteenth century continued to provide the refiners with political difficulties. The European beet sugar industry had to be artificially aided, and a system of bounties on export had been introduced on a wide scale. The European beet sugar producer received a direct subsidy from his government on sugar that he exported. This resulted in the British market being flooded with cheap raw beet sugar to the detriment of the cane producers, and a flood of cheap white beet sugar to the detriment of the British refiner. In 1902 international agreement was reached at a conference at Brussels prohibiting the countries represented

at the conference from importing sugar on which a bounty was paid. The position was greatly eased, but not for long. Indirect bounties soon took the place of state-paid bounties as trade groups within a country agreed to raise the price in their own country in order to create funds wherewith to subsidise their exports. This operated until 1928 when the British Government adjusted the scale of sugar duties in such a way as to penalise the import of white sugar.

Another political difficulty was the subsidy granted by the British Government to home-produced beet sugar. The refiners had no objection to the subsidising of sugar beet ; what they objected to was the subsidy on beet sugar. From 1924 to 1928 the assistance received by the beet sugar industry amounted to $26s. 10\frac{1}{2}d$ per cwt. or nearly twice the value of the sugar. The result was that there were soon eighteen factories eager to share this golden gift. T. & L. controlled four of these factories. These four, together with about eight others, were efficient and made profits which were almost indecent. Some factories, however, were so inefficient that they barely made ends meet. In 1936 the Government compulsorily amalgamated all the beet factories into one Government-controlled corporation. This caused a considerable increase in the efficiency of the bad factories, but as there is little incentive to efficiency it remains to be seen what the ultimate effect will be upon those factories which were efficient.

Under the Sugar Industry (Reorganisation) Act of 1936 an agreement was made between the refiners and the beet factories as to the quota of the country's trade that each is to do.

REASONS FOR A SUGAR REFINING INDUSTRY.

Two questions are often asked : Why is there a sugar refining industry ? Why cannot the raw factory produce in one single process a white marketable sugar ? There is no single simple answer to these questions. There are many answers, most of them of comparatively small importance, but all together amounting to a formidable array.

In stating these reasons the beet sugar industry must not be considered. It is an artificial industry and can in consequence often achieve success where it would fail were the artificiality removed. But many of the following arguments apply equally to beet as to cane factories.

The factory works for only part of the year—say five months. Every piece of plant installed in a cane factory can only bring a return of 5% where similar plant installed in a refinery working the whole year round would earn 12%.

As a consequence of the above, no cane factory will instal a char plant, thereby depriving itself of the best refining agent yet known.

The cane factory is usually situated far from a coalfield and is dependent on its own bagasse for fuel. In order to turn out a white sugar without char it is necessary to do a lot of remelting, which needs much fuel, which may not be available.

Any refining process, whether by char or by remelting, requires a copious supply of pure fresh water. This is often lacking in cane factories.

The cane factories are mostly situated at the back of beyond, far from the big consuming centres. They will therefore be out of touch with their customers and will not be able to deal promptly with orders or with complaints.

If sugar is marketed intermittently, for example during a five months campaign only, no good-will can be obtained. Customers are not interested in a product that can only be sometimes obtained, unless it be very cheap. Sugar sold intermittently always fetches a lower price than brands that are always obtainable.

If a cane factory wishes to build up a good-will some of its sugar must be stored for seven months. This locks up money. Sugar refined without char is always of poor quality and will deteriorate when stored for long periods in the hot climate in which cane mills are situated.

These are some of the disadvantages which face the cane producer who wishes to adventure into the refined market. Here are some of the advantages that the refiners possess.

A ready market just outside the refinery gates. The reason the refinery is situated where it is is for this very purpose.

Ability to sell a standard product, in fact several standard products and a number of specialities, every day of the year.

Ability to buy raw sugar from that particular part of the world which happens at any time to be the cheapest.

Ability to make up from one part of the world a shortage in another part. Crop failures do not spell disaster to a refiner, but the cane producer would lose all the good-will he might have been able to build up if the crop in his district fell far short of expectations.

By working twelve months instead of five, plant can be

installed in a refinery costing twice that which a factory can instal, yet the refiner gets a bigger return.

Ability of a refiner to make a greatly superior quality and thereby obtain a better price, and constant custom.

All these factors have been operating for generations, during which the questions at the head of this section have frequently been asked. The bogey of successful white sugar production by the factory has been looming over the refining industry for scores of years. It would be a rash man who said that this bogey could never materialise, but what is sauce for the factory goose may be sauce for the refinery gander, and any wonderful new process may be equally applicable to a refinery as to a factory.

RAW SUGAR PURCHASE.

T. & L. require normally some 34,000 tons of raw sugar every week. The output of most cane factories is from 30,000 to 70,000 tons in the campaign. This means that T. & L. will need the entire output of, say, forty or fifty factories. Most factories sell some of their sugar locally and only export their unsold surplus. It would be quite impracticable for us to be getting offers of sugar from, say, 200 different factories all over the world. It would be equally impracticable for all the world's cane factories to offer their sugar to some scores of refineries all over the world. The sugar broker performs the function of selling the sugar produced by the world's factories to the world's refineries.

We buy all our sugar through about half a dozen brokers whom we see and talk to every day. The cane factory by employing brokers is automatically in touch with the world's buyers.

The sugar broker is the first " middleman " in the sugar industry. In spite of popular opinion, which regards all middlemen as price-raising parasites, the broker cheapens prices by connecting the willing buyer with the willing seller. No refiner would dream of buying through a broker unless he got a better service in this way. The broker performs his service as " go between " very cheaply, and he earns every penny of the reward he receives.

Since the beginning of this century the services rendered by the broker have changed considerably. In 1900, when there were more and smaller refiners than there are to-day, the broker used not only to act as agent between producer and refiner, but used also to purchase raw sugar on his own account to anticipate the needs of the refiners, who were not in a position to buy when the producer wished to sell. The broker used therefore to act as a merchant and was an owner of warehouses both in this country and abroad. Gradually, however, with the rationalisation of the refining industry,

this function of his was no longer needed, and to-day he, for the most part, confines himself to acting as agent for the producer, making all arrangements for the prompt and safe transport of the sugar to the refiner's wharf.

In addition the broker has performed a large part in the development of our export trade. A broker has his agents in a large number of countries all over the world, and he is therefore well placed to sell white sugar for us to foreign users. His functions in these transactions are exactly similar to those in the raw sugar transactions. Our part has, of course, been reversed from being the buyer of raw sugar to being the seller of white sugar.

Sugar comes to us from, amongst other places, Cuba and the West Indies. These are our nearest cane supplies and the ship takes a fortnight or more to make the passage. The empty ship has to get there. In order to ensure continuity of supplies we should always have to buy and arrange shipment some six to eight weeks ahead were we buying from this source only. Much of our sugar comes from Australia and perhaps Java. The ship takes six weeks or more to come from Australia. To ensure continuity from this source we should need to purchase three to four months ahead.

Another reason why it is essential for us to have large purchases ahead is that our customers, the wholesalers, often wish to make forward purchases if they feel that the price of sugar may rise in the future. We wish to be in a position to be able to sell any quantity to any of our customers at any time for delivery in any period. If a customer comes to us in March to buy his supplies for August we can readily sell to him if we have already secured adequate raw supplies for future delivery. But if we have not secured them and have to go into the market to buy in a hurry we may get squeezed. Mincing Lane, like other markets, thrives on gossip. If the wholesalers buy heavily for forward delivery the brokers soon know and when we go into the market to cover our forward sales they naturally try to stiffen the price against us.

For all these reasons therefore we like to hold about 300,000 to 400,000 tons bought ahead. This is not always possible. Sometimes we hold more than 400,000 tons, but we try never to hold less than 200,000. Four hundred thousand tons is barely three months supply and is a nice comfortable figure.

We do not speculate in sugar. That is to say, we do not buy more than we need in the hope that the price will rise. We have speculated in the past, but in the long run have always found that any gains have been counterbalanced sooner or later by losses. It is just the same in all forms of gambling. On the other hand, we do not try to buy when there is no sugar offering, nor do we neces-

sarily buy the first sugar offered to us. We try to buy as cheaply as possible, and on the whole we don't do too badly.

At certain times of the year our stocks of actual arrived sugar are much larger than at other times. This is due chiefly to the fact that there are no facilities at present for storing the exportable sugars in Natal and Australia. We make special arrangements with the producers to store the sugar over here.

THE SUGAR ASSOCIATION.

Raw sugar is bought on analysis. Some kinds, Cuban, West Indian and many others, are bought on a simple polarisation basis. Others, such as Mauritius and Beet are bought on the basis of the commercial net (see Chapter 14., page 287).   In either case accurate sampling and analysis is almost as important as correct weighing.

The sugar arrives at the refinery and is there weighed, sampled and analysed.   The seller can hardly be expected to accept .the refiner's weights and analyses.   The sugar trade has therefore formed an independent body to look after both buyers' and sellers' interests and which supervises all weighing and sampling, and which carries out check analyses when required.   The costs of this body, The Sugar Association, are borne equally by buyer and seller by means of a levy of so much per ton.   The Sugar Association acts as arbitrator in the event of any dispute in connection with a raw sugar contract.   The Sugar Association is administered by a committee of representative refiners and brokers.

THE SUGAR DUTY IN THE PAST.

Any real history of the sugar duty would require many pages and would be a complicated political tale. Sugar, in almost every country, has been and is a politician's plaything.

The sugar duty was first introduced in Britain between 1660 and 1670 as a revenue-producing tax. For the next 200 years all kinds of legislation were enacted to benefit first the West Indian cane grower and then the home refiner. Very often the duty alterations helped the wrong party. For many years, until 1838, part of the duty went to pay for an export bounty on refined sugar. In 1838 the export bounty was abolished and sugar sold for export was allowed " drawback " equivalent to the duty that had been paid on it. From 1800 to 1844 the average duty was about 25s. per cwt. The Free Trade movement with its slogan of the " Free Breakfast-table " was becoming stronger, and in 1845 the duty was reduced. During the next thirty years it was reduced several times, apart from a short period of increase to pay for the Crimean War, and the duty was finally repealed in 1874. During this period

the duty arrangements were full of irritating anomalies. In a memorandum from the Scottish refiners to Members of Parliament in 1853 it was stated that if a refiner worked " out of bond " he could not export any sugar whatever. Whereas if he worked " in bond " he could sell nothing on the home market unless he first shipped his sugar to Jersey and brought it back as an import.

" IN BOND "—" OUT OF BOND."

The expressions " in bond " and " out of bond " must be understood before the working of the sugar duty is clear. An article subject to a customs or import duty must be weighed and sampled before the amount of duty can be assessed. This weighing and sampling cannot be done in mid-air while it is being transferred from ship to shore. It is therefore landed and stored in a " bonded " warehouse. Such a bonded warehouse is approved by the Crown for the receiving of goods subject to import duty where the owner of the warehouse has given his personal money " bond " that the duty will be paid before the goods are removed, unless the goods are re-exported.

If a refinery works in bond the duty is paid on the white sugar as it goes out of the refinery. If a refinery works out of bond the duty is paid on the raw sugar as it comes into the refinery. In order that the correct duty may be paid, whether on an in bond or out of bond basis, it is necessary that a duty scale be constructed so that a higher duty is paid on the higher quality sugars.

THE 1901 DUTY SCALE.

In 1901 the sugar duty was reimposed. The scale of duty is based on the polarisation of the sugar and allows for a loss in process. Polarisation is not a true measure of the available sugar (this has been discussed in Chapters 14. and 15.). But Polarisation is a comparatively simple analytical test and close agreement is reached by different chemists when testing the same sample.

There are all kinds of curious effects from this duty scale. These effects are so complicated and were so completely unforeseen that, although everyone knows the scale to be imperfect, no one wishes to start new complications by introducing an " improved " scale. This applies equally to the Government as to the refiners.

OPERATIONS UNDER THE 1901 SCALE.

The sugar duties were reimposed in 1901 after twenty-five years of duty-free sugar refining to pay for the South African War. The refiners worked out of bond. They apparently had no choice as there was no Customs machinery laid down for in bond working.

In 1903 the Brussels Convention was ratified, and it was neces-
sary that the Government should be able to certify that no sugar
went into home consumption that had received an export bounty.
A law was passed requiring the refiners to work in bond, so that
their activities could be supervised by Customs officials.

TABLE XII.

THE 1901 DUTY SCALE

Sugar	Polarisation		Per Cent.
	Exceeding.	Not exceeding.	of Duty.
	98°	—	100
	97°	98°	92
	96°	97°	89·6
	95°	96 °	87·2
	94°	95°	84·8
	93°	94°	82·4
	92°	93°	80
	91°	92°	77·6
	90°	91°	75·2
	89°	90°	72·8
	88°	89°	70·4
	87°	88°	68·4
	86°	87°	66·4
	85°	86°	64·6
	84°	85°	62·8
	83°	84°	61
	82°	83°	59·2
	81°	82°	57·6
	80°	81°	56
	79°	80°	54·4
	78°	79°	52·8
	77°	78°	51·2
	76°	77°	49·6
	—	76°	48
Molasses	Total Sugars		
	70%	—	70 ·5
	50%	70%	50.6
	—	50%	24 ·8

The duty imposed in 1901 was 4s. 2d. per cwt. for sugar over
98° Pol. In 1908 the duty was reduced to 1s. 10d. at which it stood

until 1915 when it was raised to 9s. 4d. to help to pay for the Kaiser's war.   In 1916 it was raised to 14s. and in 1918 to 25s. 8d.   In 1924 it was reduced to 11s. 8d., at which level (subject to a modification to be mentioned in a moment) it stood until April, 1939, when it was raised to 14s due to fear of war.   In September, 1939, it was raised to 23s. 4d. to pay for Hitler's war.

PROTECTION.

The Brussels Convention in 1902 put a stop to State-paid export bounties, but it could not put a stop to private agreement between the producers in a country to keep the home price high and thereby build up a fund for subsidising export.   This home-price-raising business operated to an increasing and intolerable extent until 1928, when the British Government agreed to modify the duty scale so as to penalise the import of refined sugar into this country.   This was done in the following way : the duty of 11s. 8d. was maintained on white sugar, but the remainder of the scale was reduced by the equivalent of 2s. 4d. and the refiners went out of bond.   The refiner then paid a duty on a 9s. 4d. scale so that his white sugar paid 9s. 4d., whereas imported sugar over 98° Pol paid the 11s. 8d. duty.   The home refiner received a " protection " of 2s. 4d.   The refiners did not want the money ; they wanted the removal of unfair subsidised competition.   They therefore gave the Government an undertaking that the whole of the 2s. 4d. would be passed on to the consumer.   They immediately reduced the prices of their products by 2s. 4d.   The foreign exporter therefore had to face a loss of 2s. 4d. on any white sugar exported to Britain.   The refiners were able to work full time (they had previously often had to shut down for several weeks in the year).   The public got their sugar ¼d. a pound cheaper.   By working fully the refiners were able to effect economies and were able to reduce their prices still further and yet make good profits.   No one was hurt except the foreign interests who, previously, had dumped their sugar in this country.

EMPIRE PREFERENCE.

In 1919 the British Government decided to give Empire Sugar a preference over foreign sugar.   This preference differed essentially from the protection given to the home refiner by the 1928 budget. The refiner gets security without any financial benefit, whereas the Empire Preference gives the Empire producer a direct financial benefit.   This preference is paid to the Empire producers by the refiners on behalf of the Government.   Had it not been for the co-operation of the British refiners, it would have been necessary for the Government to seek legislation to give the Empire producers a direct subsidy.   This would have been politically undesirable.

The preference works like this : the duty scale for Empire

sugars is lower than the scale for foreign sugars. The refiners have
agreed with the Government to pay to the Empire producers the
world's price plus the duty difference, or Empire Preference.
When the sugar reaches Britain the refiner pays the lower rate of
duty so that he has paid the equivalent of the ordinary non-Empire
price. The refiner has to finance the amount of the preference
that he has paid for Empire sugar from the time he pays for it on
arrival to the time he melts it. This financing by T & L of the
preference often amounts to £500,000 or more when we hold large
stocks of Empire sugar.

There are two scales of preferential duty. One for Empire
sugars in general, and one, giving a greater preference, which is
applicable to a limited amount only of certain colonial sugar. This
second scale is designed to give certain of the poorer colonial islands
a greater assistance. The amount of preference for Empire sugar
of 96° Pol is 3s. 9d. and for " certificated " colonial sugar 4s. 9d.
per cwt.

There is a considerable risk in our payment of the preference
in the price. If the preference were abolished we should have to
pay full duty on the sugar when we melted it and would have parted
with the preference. We hope that as we perform the service of
paying the preference on behalf of the Government, they would
give us adequate warning of their intention of abolishing it.

<div align="center">DRAWBACK.</div>

Working out of bond we have paid duty on all the sugar that
we have melted. Sugar duties are only payable on sugar that is
consumed in Britain. Any sugar that is exported is allowed a
Customs " drawback " or repayment of duty. This drawback is
not the highest duty rate for white sugar in the scale, but the white
sugar equivalent of the duty that the refiners pay on their raw
sugar.

Molasses that goes to cattle feed is free of duty in order that
agriculture shall not be taxed. Molasses that goes to distillers is
also free of duty in order that the spirits shall not be taxed twice
over ; once on the molasses and once on the spirit in the form of
excise duty. Molasses delivered by a refiner to a distiller or for
cattle feed purposes receives a drawback of duty corresponding to
the amount of sugar in the molasses. This molasses drawback scale
goes in steps of 10% of sweetening matter. It is very important
therefore that the molasses turned out by a refiner should be just
above one of the steps.

The molasses drawback is based on the total sugars in the
molasses, whereas the duty was paid on the polarisation of the raw
sugar. This is one of the many complications of the duty scale.

EXCISE DUTY.

Beet sugar produced in this country is subject to an excise duty which is rather lower than the Empire scale, but not so low as the certificated scale. When we melt British beet sugar we pay the excise duty just as if it were a Customs duty. The beet factory sends its sugar to us in bond. We also pay to the beet factory the difference between the full duty scale and the excise scale, thereby paying him his " preference " on behalf of the Government. Were we to buy our beet sugar duty paid, any sugar lost in transit would have paid duty and yet would not have gone into consumption.

PAYMENT OF DUTY.

We have to pay duty in advance before we can melt any sugar. Our raw sugar stores are bonded, which means that we can store sugar in our raw stores without paying duty on it. Before we can take it out to melt it we must pay duty on the amount we propose to withdraw. As we cannot pay exactly the right amount because the daily melt varies a little, the Customs make us keep a sum paid in advance equal to an average two days' melt. We then pay, every morning, a sum estimated to cover the duty on the previous day's melt.

On arrival at the refinery each cargo has been weighed and sampled. A sample has been drawn from every bag. The samples of each mark are mixed up together so as to form a true average sample of the mark. The sample is analysed by the Government chemist and in our laboratory. If our analysis does not agree with the Government analysis we do another analysis—having carefully kept the remains of the sample for just this purpose—and if we are sure we are right and the Government chemist is wrong, we ask the Customs to repeat the analysis. This they will readily do. We have to pay duty on the Government analysis ; but if we have convinced them that their first figure is wrong they will agree to accepting the new analysis.

The sugar weight is known as soon as the cargo is landed. The analysis is in due course agreed. Both we and the Customs then know how much duty must be paid on that cargo. The cargo may be melted before the analyses of all the marks or lots in it have been analysed. Or, the cargo may go into store and part of it may stay there for a year or more. It does not matter. The Customs see to it that we are always two days ahead with our payments, and as the cargoes are completed each one is finally settled.

ADVANTAGES AND DISADVANTAGES OF A SUGAR DUTY.

From the point of view of the Exchequer the sugar duty is a

good form of taxation. Sugar is cheap and is used by everyone. The tax, unlike one on tobacco, beer or lipstick bears on everyone. An increase in the price of sugar of 1*d*. a pound is not a fearful hardship, but it brings in about £16,000,000. The tax is very easily and cheaply collected. The writer would hazard a guess that after paying for the cost of collection, 99·75% of the duty reaches the Exchequer. It is unlikely that there are any other taxes which are more cheaply collected.

From the point of view of the refiner the tax is bad. The cheaper an article is, the more can be sold and the more certain is the demand.

A great disadvantage to the sugar trade of the sugar duty is the dislocation of trade when budget day approaches. If the trade thinks that there may be a rise in duty they buy as much sugar as they can. After the budget, whether there was a change or not, the trade is stagnant for weeks. If the trade thinks that there may be a fall in duty they hold off buying for weeks before the budget and we have frequently had to shut down. After the budget there is a wild rush to get supplies.

When a duty change occurs the refiners either lose a lot of money or make a little. When the duty goes up they get a big profit on their unsold duty paid sugar. But their unsold stock under these conditions is generally low because the trade has probably anticipated the change and has bought heavily. When the duty goes down the refiners make a severe loss because they have paid the duty on their unsold stock and then have to sell it at the reduced price corresponding to the new lower duty. In this case their unsold stock is heavy because the trade have feared a duty reduction and have withheld their buying orders for weeks before. The Government must keep their budget intentions secret, lest speculators should buy heavily for a rise in duty, or sell heavily if they expected a fall in duty. The only time a duty change has been revealed in advance was in 1928 when it was necessary for the Government to arrange for the refiners to go out of bond. Of course, when the duty was imposed in 1901 the refiners had to be consulted on the scale.

If a duty were imposed on sugar, but other sweet things were free from duty, sugar would be unfairly penalised. When the sugar duty was imposed, glucose and saccharin were also subjected to duty. This duty was such that it was very roughly proportional to the alleged sweetening power. If a person satisfies his desire for sweet things by eating raw sugar, refined sugar, solid glucose, liquid glucose or saccharin, he will have paid approximately the same amount in duty.

STORY OF A TYPICAL RAW SUGAR TRANSACTION.

One morning in January we decide to buy a cargo of 8,000 tons of sugar from a broker. He has probably been offering this cargo to us for some days. We have told him that his price is too high. He has told us that our counter-offer is too low. Eventually agreement is reached. What has been done at the interview is that we have said that we will buy a cargo of between 7,600 and 8,400 tons (depending on the size of the ship) at, say, 6s. c.i.f. for June arrival. C.i.f. means that the price includes c. the cost of the sugar, i. the insurance, and f. the freight. The price is always spoken of in shillings per hundredweight. (This is the same figure as pounds per ton.) That afternoon we receive a contract from the broker confirming the verbal transaction and setting out all the terms that have been agreed between us. When we and he have signed the contract we are bound to take and pay for the cargo and he is bound to deliver it.

Some weeks will probably pass. One morning the broker tells us that he has chartered the good ship " Mildew " to carry the cargo. We ring up Mr. Mill, the shipowner, and ask him to let us know as soon as he can when he expects his ship to load, sail and reach London. He promises to do so.

More weeks pass. Mr. Mill then rings up and says that the " Mildew " should sail from Kingston, Jamaica, on May 17th, and should reach London about the 1st June.

Mid-May arrives and Mr. Mill tells us that S.S. " Mildew " sails to-morrow and should reach London about the 2nd June. From time to time we hear news as to the progress of the voyage, and we inform our lighterage company, Silvertown Services, that they must have craft ready to take the " Mildew's " cargo about June 3rd.

On the evening of June 3rd we are told that the ship is off Gravesend. We at once have to make " entry " with the Customs. This means that we inform the Customs that we have a ship carrying a cargo liable to sugar duty at Empire rate about to enter port. That night the ship berths, and first thing next morning we receive a bundle of papers. The first is the " charter party," which is a document setting out the exact terms upon which the shipowner has agreed to carry the cargo. (We generally receive the charter party some days in advance of the ship's documents). We must check this document, because in our contract with the broker we made certain stipulations ; for example, we specified that, although the shipowner is responsible for paying the stevedores for unloading the ship, we were to have the naming of the stevedores who were to do the job. Mr. Mill might have slipped in a clause stating that his

brother-in-law Mr. Dew was to unload, or he might have stipulated that before any cargo could be lifted we had to paint the funnel sky-blue (charter parties sometimes contain very queer conditions). The second document is the " bill of lading." This tells us that the ship loaded with 8,346 tons of raw sugar. We must make sure that the cargo is right before we accept it. It might have been 7,000 tons of castor oil beans. The third document is the " certificate of origin." This certifies that the sugar was grown and produced in Jamaica, one of His Majesty's Colonies. Without this certificate we should have to pay duty at the full rate.

When we have satisfied ourselves that all these documents are in order we do three things. We send the certificate of origin to the Customs. We instruct Silvertown Services and our stevedores to get on with the unloading. We pay the broker 98% of the approximate value of the cargo.

The cargo reaches the refinery where every bag is weighed and sampled under the supervision of the Customs officers and the officials of the Sugar Association. The sample is analysed by the Government chemist, by the seller's chemist and by our chemist. We pay duty on the Government analysis, protesting if the Government analysis differs materially from ours. We pay for the sugar on the average between the seller's analysis and our own. If the two analyses differ by more than $\frac{1}{4}\%$ an independent analysis is made by the Sugar Association and payment is made on the average of the two nearest analyses. The broker is now in a position to send us his final account which we pay. The deal is finished.

The broker has performed the following services : he found a seller in January who had May sugar at a certain price. He has to pay the seller in his own money, so he had to buy the currency in the seller's country. He had to charter the ship. He had to arrange the insurance. To fix his price to us in January he had to estimate the cost of all these, together with the cost of discharging the cargo in London. If he is able to make a profit on these things he is lucky. His reward is a commission of about $\frac{1}{2}\%$ paid by the seller.

THE DISTRIBUTIVE TRADE.

There are nearly 100,000 grocers in Great Britain. If we were to try to sell direct to all of them we should have to have about 250 travellers if each grocer was to be visited once a month. The usual small grocer sells sugar, tea, coffee, cocoa, mustard, pepper, salt, vinegar, jam, marmalade, honey, syrup, cheese, eggs, butter, margarine, sago, rice, tapioca, semolina, sardines, salmon, fruits, meats, dates, raisins, currants, sultanas, soap, polish, etc., etc.— often two or three brands of the same article. He sells at least 100 different things. If each article had to be bought from a

separate concern the grocer would have to see half a dozen travellers every day. The poor man would have no time to attend to his own customers. He would have to write orders to 100 different concerns. He would have to pay 100 different bills. His post would be vast. His life would be a misery. Everything he sold would cost more because each article would have to bear the cost of all these thousands of travellers. The railways would be overcrowded. The car parks would be thronged with travellers cars. The grocer would have to employ an assistant to do his selling for him because he would be swamped in a sea of paper.

The wholesaler sends out his army of travellers who can sell to each grocer any one of 100 different articles. One visit a month is all the grocer needs. He gives one order. He gets one account. He pays one cheque. He does not need an assistant. He has plenty of time to deal with his customers. The 100 concerns whose products he sells need have no travellers or at most a few visitors to get first-hand information regarding the public's tastes and complaints.

THE WHOLESALER.

The wholesaler is the second " middleman " in the sugar trade and like the broker, he serves to cheapen the cost of the article by connecting the willing buyer with the willing seller very efficiently.

The refiners sell their refined product to the " Trade " on the quantity rebate system. That is to say, a buyer will get different rebates according to the amount of sugar that he buys at one time. As a result, the great majority of our sales are done in the quantities which earn the biggest rebate. The quantity rebates in force in 1939 were :—

QUANTITY—TONS	PENCE PER CWT. REBATE	
	Bulk.	Packets.
100 and over . . .	$4\frac{1}{2}$	6
50 and over up to 99 .	3	$4\frac{1}{2}$
10 and over up to 49 .	$1\frac{1}{2}$	3
5 and over up to 9 .	0	$1\frac{1}{2}$

In addition to these rebates the buyer receives a discount of $1\frac{1}{2}\%$.

The refiners' chief customers are wholesale dealers, the Co-operative Wholesale Society, large multiple shop owners and large manufacturers of jam and confectionery.

DISTRIBUTION.

Before the growth of our packet trade all sugar was sold " ex refinery " or " ex depot." This means that the buyer pays the cost of delivery from the refinery or depot to the shop or manu-

facturer's premises. Most of the depots are free ; that is to say no charge is made for delivering to these free depots. Some depots that are far from the refineries carry a small charge. These " terms of sale " have continued for bulk sugar.

Very different terms of sale, however, exist for packet sugars. In the case of packets we sell " delivered to one address in minimum quantities of 3 cwt.," the cost of delivery being included in the price. We arrange a suitable allowance, to be deducted from the price, to ceitain customers who wish to make their own delivery arrangements.

A few years ago T. & L. started their own transport company, and to-day a very large proportion of free delivery is done by this concern. Its organisation is highly complicated as can be imagined when it is pointed out that the packet sugar delivery list from London refineries is a book of 200 pages and shows the days on which delivery is made to some 10,000 towns and villages. Every town or village shown in the list gets a delivery at least twice a week.

STORY OF A TYPICAL REFINED SUGAR TRANSACTION.

One morning a wholesale dealer comes to our sale room (or more probably telephones) and says that he wants to buy 100 tons of sugar divided into several qualities. Thereupon a " sales advice " is made by our sale room, who keeps one copy, sends another to the invoicing department and a third to the refinery. The invoicing department is responsible for sending the buyer a bill and for seeing that the bill is paid. The refinery enters the sale into the " customers' stock book." The simplest thing which can now happen is that the customer sends delivery instructions for perhaps as many as fifty shops. These instructions are passed to the transport company, who advise the refinery when the deliveries have been made. The refinery makes a suitable entry in the customers' stock book.

Instead of this, the buyer may sell the sugar to customers who wish to collect the sugar themselves. The buyer gives these customers an order to collect from the refinery and each time a van or lorry arrives at the refinery with such an order, sugar is given to the driver and the quantity is " written off " in the customers' stock book. If the buyer makes a mistake and sends for more sugar than the amount which stands to his credit in the customers' stock book the van is not loaded until the buyer has bought some more sugar from the sale room (this he can do in three minutes by telephone).

Lastly the buyer may decide that he wants to issue delivery orders so that his customers can draw their sugar from, say our,

Bristol depot.   The refinery is advised of this, and they close the account at the refinery.   The depot keeper is also advised, and he acts in exactly the same way as the refinery do when there is no such " depot transfer."

If sugar is not withdrawn after twenty-eight days from the date of the sale, we reserve the right to charge rent on the sugar.

Immediately the sugar is sold our invoicing department sends the bill to the customer.   Our terms of sale include payment within fourteen days, but as we give a small discount for cash, we generally get paid by return of post.   We also reserve the right to ask for payment in advance.   This is a right we seldom exercise, but if a small customer buys a very large amount of sugar and we are of the opinion that he is speculating, we ask for our money first.

These wide and flexible delivery services bring in their train very complicated accounting and cause many grey hairs to those responsible for seeing that no customer gets more or less than his due.

FINANCE.

The financing of a large undertaking requires a lot of money, which must somehow or another be forthcoming.   Let us look for a moment at the money T. & L. normally need.   We buy raw sugar which must be paid for as soon as it arrives.   We frequently hold 150,000 tons of arrived sugar.   (We have sometimes held over 400,000 arrived and paid for.)   We have paid preference to the Empire producer on a large part of this raw sugar.   We have paid duty on our stock in process and on our refined stock in warehouse. We do not get paid for refined sugar until some days after we have invoiced it.   The stock of raw sugar may be worth £900,000. The Empire preference may amount to £400,000.   The duty on stock in process and stock of ıefined in warehouse may have amounted to £500,000.   Our refined sugar in warehouse and unsold stocks in depots may be worth £800,000.   These add up to the formidable total of £2,600,000.   In addition we carry large stocks of coal, chemicals, bags, paper, cardboard, tinplate, engineering and electrical spares, etc.   We must also find, without fail, the wages and salaries.   So that the total sum of money that we have had to find is over £3,000,000.   This money is called working capital, and an examination of our balance sheet will be necessary to show where it comes from.

BALANCE SHEET.

On pages 344, 345 is one of T. & L.'s recent balance sheets. The man-in-the-street generally considers a balance sheet to be so much waste paper.   Everything seems to be on the wrong side, and things that he would call assets are called liabilities, and so on.

The balance sheet of a company, partnership or any other enterprise is a statement which shows the owners of the money which has been used in the enterprise, in what way the money has been used. Before considering T. & L.'s balance sheet, which is rather complicated, a simple example will be given.

A man wants to buy a bungalow and start chicken-farming in a small way. He has £200 of his own. He can borrow £300 from a friend. His bungalow and the plot of land it stands in are going to cost £600. He approaches his bank who agree to give him a mortgage of £300 on the bungalow. So he goes ahead, buys the bungalow, builds chicken houses, buys food-cookers and other gear, purchases pullets, sells eggs, and at the end of his first year produces a balance sheet which will look something like this :—

LIABILITIES.	£	ASSETS.	£	£
Own capital . . .	200	Bungalow and land .	600	
Loan	300	Hen houses . .	120	
Mortgage . . .	300	Plant . . .	15	
Sundry creditors . .	6			
Reserve Fund . .	40	Total fixed assets .		735
Profit for the year . .	26	Chickens . .		85
		Stocks of eggs and egg-boxes . .		12
		Feeding stuffs .		8
		Sundry debtors .		12
		Cash in hand and at bank . . .		20
	£872			£872

His liabilities are sums of money he is liable to account for. His assets are the actual things on which he has spent the money. The first three items on the left-hand side are the sums of money that he had or had borrowed to start up. The sundry creditors are his unpaid bills, which are made up of, say, £4 for feeding stuff and £2 for carriage on his eggs. The next two items show that he has done well and is a prudent man. His real profit is £66, but he has wisely set aside £40 as a reserve, leaving the balance of £26 as a profit. Now on the right-hand side he sets out the manner in which all the sums on the left-hand side have been spent. The first two are the actual costs of his bungalow and his hen houses. Next year they will have deteriorated slightly, and if he is wise he will reduce the amounts set against them by knocking off a small " depreciation " to cover their loss in value or by setting aside a

depreciation reserve, or by so maintaining them that their value does not deteriorate. The item for plant covers food boilers, feed bins, etc. These items together comprise his " fixed " assets— that is to say the assets which are tangible permanent things and not part of his working stock. The next three items are his working stock which vary in amount and value from time to time. The sundry debtors are the people, wholesale grocers or poulterers, who owe him money for his eggs and chickens. The last item is the real stumbling block in the balance sheet. If his profit is £26, why has he only got £20 in the bank ? Again, if he has set aside £40 as a reserve, where is it ? Taking the first question first ; suppose that all the people to whom he has sold goods paid up at once there would be no item of sundry debtors, and the cash in bank would have stood at £32. But this would not have made the slightest difference to his profit. His reserve of £40 he has wisely employed in helping his business by carrying a bigger stock of feeding stuffs and boxes and keeping more fowls. If he had not had this reserve in hand and yet had still held the same amount of fowls and stocks, one of two things would have been necessary. Either he would have got behind with the payment of his bills, when his sundry creditors would have stood at £46, or he would have had to borrow more money.

A profit does not necessarily mean cash in the bank. It means that there are more goods, or more buildings, or more plant (or more cash) than is necessary to account for the money with which the enterprise started.

A reserve fund does not necessarily mean cash in the bank— in fact it hardly ever does. Generally, money put into reserve is used for improving the business by building extensions, or the holding of increased stocks, or perhaps by investing money in other concerns.

Having now cleared away certain stumbling blocks, the T. & L. balance sheet should be quite comprehensible. The balance sheet for 1938 is given on pages 344 & 345.

When a company is formed to which the public are to be allowed to lend their money—that is to say in which the public can invest, certain legal formalities have to be complied with, one of which is a statement to the registrar of public companies (an official of the Inland Revenue Authorities) as to the amount of capital that it is proposed should be borrowed. This amount of capital is " authorised " by law, but it does not follow that the directors of the company will wish to borrow all this money at once. They may wish to have the power of being able to " issue " more shares— that is to say, to borrow more money from the public at any time

CAPITAL AND LIABILITIES.

		£
Capital		
Authorised.		
1,100,000 6½% Cumulative Preference Shares of £1 each . . £1,100,000		
5,100,000 Ordinary Shares of £1 each 5,100,000		
	£6,200,000	
Issued and fully paid.		
1,100,000 6½% Cumulative Preference Shares of £1 each		1,100,000
5,000,000 Ordinary Shares of £1 each . .		5,000,000
		6,100,000
4½% First Mortgage Irredeemable Debenture Stock		500,000
5½% Mortgage Debenture Stock.		
Amount as at 30th September, 1937 £1,210,400		
Less amount redeemed during period 14,678		
		1,195,722
Debenture Stockholders, interest accrued . .		5,625
Sundry Creditors.		
Trade and General, including provision for accrued and estimated charges £2,069,967		
Subsidiary Companies . . . 10,303		
Other Associated Companies . 505		
		2,080,775
Depreciation Reserve		300,000
Dividend Reserve		100,000
Taxation Equalisation Reserve		150,000
General Reserve		2,100,000
Profit and Loss Account . . . £1,006,817		
Less Interim Dividends paid 15th June, 1938 238,050		
		768,767
		£13,300,889

1st. OCTOBER, 1938

ASSETS.

	£	£
Freehold Land and Buildings as at 30th September, 1937, at cost	2,852,019	
Additions during period at cost	204,320	
		3,056,339
Leasehold Property as at 30th September, 1937, at cost, *less* depreciation		12,841
Cottage Property as at 30th September, 1937, at cost *less* depreciation	25,873	
Additions during period at cost	732	
		26,605
Plant and Machinery, Utensils, Furniture and Fittings, as valued by the Directors in 1923, with subsequent additions up to 30th September, 1937, at cost, *less* depreciation	3,963,894	
Additions during period, at cost	165,607	
		4,129,501
TOTAL OF FIXED ASSETS.		7,225,286
Investments.		
In Subsidiary Companies	865,714	
In other Associated Companies	630,016	
General	14,789	
		1,510,519
Stock of sugar, syrup, materials and stores as valued by the Directors		2,678,777
Sundry Debtors.		
Trade and General including charges paid in advance	1,270,816	
Subsidiary Companies	22,722	
Other Associated Companies	18,095	
		1,311,633
Cash at Banks and in Hand		574,674
		£13,300,889

without having to go through a lot of tiresome formalities. It will be seen that £100,000 of the " authorised " capital in the form of ordinary shares was not issued in 1938.

It will be seen that we have two forms of capital. Ordinary shares and preference shares. A preference share is one which receives preference over ordinary shares. That is to say that the interest on the preference shares must be paid before any interest is paid on the ordinary shares. The preference share never receives more than the stated interest, in our case 6½%. Cumulative means that if in any year there is insufficient money in the profits to pay the interest on the preference shares, this back interest must be paid up before any interest can be paid on the ordinary shares. Preference also means that in the event of the Company having to go out of business due to bad luck or bad management, the Preference Shareholders would have the right to any available assets of the Company before the Ordinary Shareholders. Ordinary shares receive the balance that is left after the preference shareholders have received their current interest and back interest, if any. Ordinary shares therefore may be subject to great fluctuations in the rate of interest they receive. They may receive little one year and a very large sum the next.

Debentures are the same as an ordinary mortgage on a house, except that the actual mortgage is in the name of trustees who watch the interests of the debenture holders and see that the value of the security, on which the mortgage has been raised, is maintained. The public buy shares in the mortgage, and these shares are called debentures. The first mortgage pays a small interest. It is a very safe form of investment for those people who want to lock up their savings in something that they will not have to worry about again. Irredeemable means that we cannot decide to pay off this debt the way an ordinary houseowner can decide to pay off his mortgage if he backs an outside winner. The first mortgage debenture holders have the very first call on our plant and buildings and must receive their interest before anyone else. The actual part of our property which is the security for our first mortgage is Thames refinery and part of our Liverpool property. The 5½% debentures receive their interest after the first mortgage holders have been paid. In order to make this investment tempting to the public a higher rate of interest is paid. As we do not want to be saddled in perpetuity with a huge debt this mortgage is redeemable —that is to say we can gradually pay it off. The security for the second mortgage is our Plaistow Wharf refinery and the remainder of our Liverpool property. The item of £5,625 of debenture interest represents those forgetful debenture holders who have forgotten to pay in their interest warrants to their banks. The total amount of money that we have borrowed in one way or another from the public

therefore amounts to some £7,800,000. From the right hand of the balance sheet it will be seen that the total amount of our fixed assets was some £7,200,000. The difference of £600,000 represents part of our working capital.

Continuing our examination of the left-hand side, sundry creditors are all the people to whom we owe money and consist of two major items, raw sugar and income tax.

Our reserve funds amounted to some £2,650,000 and have reached this figure by yearly sums set aside out of profits. In the year of this balance sheet £300,000 was set aside out of profits to reserve. Most of this money is placed to general reserve, but a certain amount is set aside to provide for certain specified risks. Undue depreciation of our fixed assets, an unfavourable alteration in taxation arrangements and a sum wherewith we can pay a small dividend in a bad year in which we have made no profit. The last item on the left is the profit for the year.

The items of fixed assets on the right-hand side call for no explanation, except that the additions to plant and buildings are practically covered by the amount transferred to General Reserve (this is shown in the Profit and Loss Account, not reproduced here.) These new work items consisted, in the year in question, of part of the new loaf house at Thames and part of the recovery house and yellows house at Liverpool and final items in the pan house at Plaistow.

Subsidiary companies consist of companies which we control by owning more than half their share capital. Cane factories in Jamaica and Trinidad, John Walker & Sons in Greenock, our lighterage and transport companies, Silvertown Services and Pease. Associated companies are companies in which we do not hold a controlling interest, and this item represents chiefly our holding of shares in the British Sugar Corporation which took over our four beet factories when all the beet factories of the country were compulsorily amalgamated.

Stocks are self-explanatory. Sundry debtors consist chiefly of customers who have bought sugar but have not yet paid for it. Cash in bank and in hand represents less than half the net profit we made during the year—just like our chicken farmer.

It is impossible to say that one lot of assets covers any particular part of the liabilities. But it will be seen that we hold stocks of sugar and stores which just about cover all our reserves. If we sold all our stocks we should have an extra sum in the bank which would amount to the total of our reserves (but, of course, we should not be able to carry on like this).

By looking at one balance sheet it is difficult to get an exact idea of the strength of a company. Successive balance sheets must be examined and compared to see whether the concern is being prudently managed.

For the year covered by this balance sheet we paid a dividend of $18\frac{1}{4}\%$ on the ordinary shares. Ill-informed people often consider that such a dividend indicates profiteering. The rate of dividend paid by a company on its ordinary shares is really no indication whatever of its prosperity. A company may have a small ordinary capital, but, by years of prudent management, may have built up a large business by setting aside big reserves. The ordinary capital may be no indication at all of the actual capital employed, nor is the rate of dividend any indication of the profit.

The capital employed is shown by all the sums on the right-hand side of the balance sheet adjusted for the difference (if any) between the sundry debtors and the sundry creditors. If we paid all the creditors and had been paid by all our debtors we should have had £769,642 less in cash or stock on the right-hand side. We have the use of our creditors' money as working capital to finance our debtors, so that the difference between the two is the only correction we need apply. So we deduct £769,642 from the total assets of £13,300,889 to find the actual capital of £12,531,747.

In 1938 T. & L. show a profit of £1,006,817 on the balance sheet, but the actual earnings before transferring any sum to reserve, neglecting the balance carried forward from the previous year and adding the interest of £89,072 paid to the debenture holders, was shown by the profit and loss account to be £1,446,958. That is a profit on the capital employed of $11\cdot6\%$, hardly an exorbitant rate in a very prosperous year on a business subject to such fluctuating influences as sugar refining.

Another ill-informed argument is that it is wrong for a concern to make more than a million out of feeding the people. This statement merely shows that the size of the business is not appreciated. In 1939 T. & L. turned out about 140 lb. sugar every second, day and night, Sundays excepted. A small village grocer also feeds the people. He may own a shop, stock, etc., worth in all £1,350. Would anyone dream of criticising him if he made sixty shillings a week ? Rather would he have public sympathy for only earning the same money on his capital as is earned by T. & L.

BRIEF HISTORY OF TATE & LYLE LTD.

Henry Tate, the son of Rev. William Tate, was born at Chorley, in Lancashire, in 1819. At the age of thirteen he was apprenticed to a grocer in Liverpool. At twenty he started a grocery business of his own which, owing to his wisdom and energy, soon became

prosperous. About 1859 he became a partner in the firm of John Wright & Co., sugar refiners in Liverpool. The partnership continued until 1870 when John Wright & Co. were merged into a new concern called Henry Tate & Sons, who built the refinery at Love Lane in 1872. In 1876 Tate's acquired the " Langen " process for making cubes and in 1878 the Thames refinery at Silvertown was built as a cube-making house. A great and valuable trade in cubes was built up. In 1894 the Langen process was replaced by the " Adant " process. This was a bold experiment. The cost was tremendous, but so was the success of the much improved product and process. The Company grew and prospered.

Abram Lyle, the son of Abram Lyle, a cooper and shipowner in a small way, was born at Greenock in 1820. He started work in a lawyer's office, but soon found out that he did not care for the law and went back to his father to serve an apprenticeship as a cooper. He indulged in a number of small shipping transactions under the name of Abram Lyle & Co., chiefly the importation of sugar from the West Indies, and he gradually built up, with his great friend and partner, John Kerr, a shipping concern of some importance. In 1865 he became senior partner in the Glebe Sugar Refining Co. In 1882 he decided that the way to success was to put his refinery in the middle of a big consuming market. He decided to sell out his interest in the Glebe, and he sent his sons to London to build a large refinery in West Silvertown at Plaistow Wharf, to do business under the name of Abram Lyle & Sons. The Company grew and prospered.

Although both Tate's and Lyle's prospered, they each had to find prosperity in a speciality as there was for years little or no profit to be made out of granulated sugar owing to subsidised foreign competition. Tate's had made a wonderful name for Cubes and Lyle's had made Golden Syrup a high-class product instead of an indifferent by-product. Both these specialities have been household words for two generations.

In 1921 the two concerns got together with a view to amalgamation, and joined forces on a fifty-fifty basis as Tate & Lyle Ltd.

CHAPTER 17. APPENDIX.

" The time has come," the Walrus said,
" To talk of many things :
Of shoes—and ships —and sealing-wax—
Of cabbages—and kings —
And why the sea is boiling hot—
And whether pigs have wings."

CARROLL—Through the Looking Glass—1872.

The Confused Names of the Sugars—Comparative Value of Cane Sugar and Glucose—The Rise in Popular Admiration for Glucose—The Digestion, Storage and Use of Sugars in the Body—The Unique Value of Sucrose as a Food—The Medical Value of d-Glucose—The Use of Glucose in Confectionery—Crystals—The Sucrose Crystal—Heat of Solution and Heat of Crystallisation—Le Chatellier's Principle—Water of Crystallisation—Twinning and Adhesion of Crystals—The Adant Cube Process—The Hübner Cube Process — Critical Speed of Centrifugal Machines — Syrup on the Face of a Centrifugal Machine — Centrifugal Force — Loss Due to Heating Effect of Electricity—The Voltage in a Three-phase Circuit—The Properties of Pure Sucrose Solutions and Crystals—Books on Sugar.

This chapter is somewhat of a junk heap. It contains things which, owing to their somewhat technical character, were purposely omitted from the main chapters. Other matters were found a place here because there was no real home for them elsewhere.

THE CONFUSED NAMES OF THE SUGARS.

" Cane Sugar " is the non-technical chemical name for the substance whose technical name is " Sucrose "—the white crystalline sugar of the table. It was called " cane " sugar because it was first isolated from the sugar cane. When sucrose was first extracted from beet it was called " Beet Sugar," although it was in fact sucrose or cane sugar. Beet sugar is generally looked upon by the public, and by part of the medical profession, as inferior to cane sugar. Perfectly refined beet sugar is identical with the pure product obtained from the cane. No scientist has yet discovered any test which will determine whether a sample of pure sucrose originated from cane or from beet. In spite of the strong opinion to the contrary held by most apiarists, no bee can tell the difference either. The reason why beet sugar has a bad name is that in the past much

imperfectly refined beet sugar was sold. The potash salts in impure beet sugar reduce the sweetening power and give bees diarrhœa.

When a solution of "Cane Sugar" is treated with acid, a mixture of equal parts of two simpler sugars results. This mixture is called " Invert Sugar," and the two sugars composing it are " Dextrose " and " Lævulose." Unfortunately these sugars have each got two other names. Dextrose is called " Grape Sugar " or " *d*-glucose " and lævulose is called " Fruit Sugar " or " *d*-fructose." The mysterious " *d*- " in front is a chemical symbol indicating the arrangement of the atoms in the molecule. There are sugars known to the chemists called " *l*-glucose " and " *l*-fructose." The " *d*- " and the " *l*- " do not refer to the right- or left-handed polarisations of the sugars, but to the right- or left-handed arrangement of the atoms in the molecules.

When starch is treated with acid it breaks down into successively simpler substances, " Dextrin " or gum, " Maltose " or malt sugar and finally " Dextrose " or *d*-glucose. In medical books the words " glucose " and " dextrose " are used interchangeably to mean the same substance. Some of the older generation of sugar technologists use the word " glucose " to mean invert sugar. The most common use of the word is for the starch product which contains dextrose in quantities which vary from under 20% to over 40%. In the paragraphs which follow " glucose " means the starch product of unspecified composition.

COMPARATIVE VALUE OF CANE SUGAR AND GLUCOSE.

Pure dextrose obtained from the inversion of cane sugar is identical with that produced from the breakdown of starch. Dextrose has about 70% of the sweetening power of cane sugar. The calorific value of dextrose is 5% less than that of cane sugar. The sugar in human blood is present chiefly in the form of dextrose. There is frequently a small amount of lævulose circulating also.

Whenever cane sugar is inverted, equal parts of dextrose and lævulose result. Lævulose has the same calorific value as dextrose, but has about 170% of the sweetening power of cane sugar. (Sweetness figures are difficult to arrive at and are indicative rather than exact.)

Glucose consists of a mixture of compounds resulting from the incomplete breakdown of starch. On the next page are a few analyses of typical glucose syrups.

Maltose is a sugar somewhat similar to sucrose. It can easily be broken down into the simpler sugar, dextrose. Maltose has the same calorific value as cane sugar, but has only about 35% of the sweetness.

Dextrin, the gum of postage stamps, and the major constituent of most commercial glucoses, has a calorific value similar to that of the sugars and is readily digested ; but it can hardly be looked upon as satisfying the requirements of a food.   Among the essential qualities of foods, for the correct flow of gastric juices, are appetising taste and consistency which are absent from dextrin. (Does the mouth water at the thought of gum roly-poly ?)   The gastric juices are not needed for the digestion of the sugars, but they are necessary for the digestion of the proteins and fats which form part of any meal.

GLUCOSE SYRUPS.

	A	B	C	D
Dextrose . .	14·7	21·2	47·6	58·6
Maltose . .	28·8	20·2		
Dextrin . .	56·5	58·6	51·9	40·3
Other substances .	Tr	Tr	0·5	1·1
	100·0	100·0	100·0	100·0
Water in sample .	21·3	19·3	19·0	18·0
Approximate sweetness of solids (Sucrose = 100)	21	22	25	30

Up to the year 1927 the price of cane sugar was such that the manufacturers of cheap jams and cheap confectionery found in glucose an economical substitute for part of their sugar.   The useful place of glucose in confectionery is discussed later on page 358.

Under some conditions glucose is considered an adulterant. For example, a number of successful prosecutions have taken place in Great Britain against vendors of syrups containing glucose when these were sold as " golden syrup."   " Golden syrup " was held by the courts to have become a name for a by-product of sugar refining, and the addition of glucose was held to be an adulteration. Jams may not carry the British National Mark if they contain glucose.

THE RISE IN POPULAR ADMIRATION FOR GLUCOSE.

From 1927 to 1930 the world price of sugar fell from a 14s. level down to a 7s. level, so that the makers of cheap jams and cheap confectionery found that the price of glucose compared to that of cane sugar was such that they had little advantage over the makers of higher class goods.   They therefore had to compete on quality and turned away from glucose.   At the same time the commercial

production of a fairly pure form of dextrose from starch became practical. Certain glucose and dextrose manufacturers hit on a truly brilliant advertising idea ; namely, that as the human body uses sugar in the form of d-glucose (dextrose) then d-glucose was the "natural," "vitalising," "predigested," "energising," etc., sugar, because it could go straight into the blood stream all ready for use without digestion. This argument was so simple and so specious that it quickly spread right round the world, and the public and most medical men accepted it without question.

THE DIGESTION, STORAGE AND USE OF SUGARS IN THE BODY.

Sugar is a body fuel. It provides heat and muscular energy. It does not contain any of the substances necessary for bone-building or tissue repair. It contains no vitamins. These substances are not removed in the refining process. They are not present in the raw sugar.

Because brown bread contains valuable dietetic properties absent from white bread, there is a widespread belief that brown sugars are superior to white sugar. This belief is quite contrary to the facts. Raw brown sugars contain many objectionable impurities. These comprise cane trash, soil, other dirt and various forms of life—bacteria, moulds and live sugar lice (carpoglyphus anonymus —often also called acarus sacchari) which are sometimes present in enormous numbers. These impurities are removed in the refining process and are absent from white sugar, " pieces " or soft sugars and certain specially prepared West Indian brown sugars. The brown colour in brown sugar is due to organic colouring matters—caramel, etc.—which have no dietetic value.

When work is done by the body, sugar is " burnt " in the body and the energy liberated warms the body and provides the energy for doing the work. Sugar, eaten as such, is only a small provider of this fuel. All the starch in bread, potatoes, rice, etc., is converted into sugar before the body can use it. Some of the protein in meat, fish, eggs, etc., is also converted into sugar. About 1 lb. of sugar a day passes from the digestive organs to the liver in a normal man on normal diet.

The body uses its sugar chiefly in the form of dextrose, but stores it in the form of glycogen or animal starch. The amount of sugar—dextrose—circulating in the blood is quite trifling. A normal man has about 12 lb. of blood circulating in his body. In health the amount of dextrose in the blood is about 0·10%. If it rises to, say, 0·18% the owner of the blood has got diabetes. If it falls to, say, 0·06% the owner is suffering from extreme exhaustion or an overdose of insulin. It is clear that a very small variation in the amount of blood sugar—less than a teaspoonful—may be the difference

between health and serious illness.

When cane sugar is eaten it passes right through the stomach and duodenum unchanged. Now it might be thought that this might be a rather slow process, but in fact, it is exceedingly rapid. Sucrose in solution seems to pass out of the stomach almost as soon as it enters it. It does not have a prolonged stay there, like a piece of baked potato or a piece of boiled pork, which may make its presence uncomfortably felt after some hours. If a man takes a solution of cane sugar before breakfast there is a rise in the dextrose of the blood, and lævulose is found there, within a few minutes. In fact the rise in blood sugar after taking cane sugar is normally just as rapid as after taking the same amount of dextrose. This is a remarkable and proven truth. In the small intestine cane sugar meets the enzyme, invertase, which inverts it into dextrose and lævulose as it is passing through the intestinal walls. (Enzyme, Greek, en—in, zume—yeast.) An enzyme produces a chemical action without being changed or taking part in the action itself, just as acid causes inversion but is left intact itself. After inversion in the intestinal walls the sugars pass, via the portal vein, to the liver.

When dextrose is eaten it passes through into the small intestine where it is absorbed and passed to the liver where it is dealt with as described below. If the assertion of the glucose advertisers were true, that dextrose passes straight into the blood stream, a tablespoonful of dextrose would cause the sugar content of the blood to rise to 0·50% As the kidneys will not tolerate a blood sugar content of more than 0·18% they would immediately reject the excess into the urine.

When starch is eaten in the form of potatoes, bread, rice, etc., digestion commences in the mouth due to an enzyme, ptyalin, in the saliva. This starts to break the starch down into the gum dextrin and then into the sugar maltose. After about half an hour in the stomach the partly simplified starch ceases to change owing to the action of the ptyalin being arrested by the stomach acid. The complete breaking down of the starch and dextrin into maltose is done in the duodenum by the action of the enzyme diastase or amylase which is produced by the pancreas. The sugar maltose is broken down in the small intestine by the enzyme maltase into two parts of the simple sugar dextrose. This is passed to the liver.

The sugar in milk, lactose, passes into the small intestine where the enzyme lactase breaks it down into the two simple sugars, galactose and dextrose, which are passed to the liver.

The body is provided with a special enzyme for breaking down each of the more complex sugars into the simple ones. Many food

cranks make the statement that sucrose is an unnatural food. This can hardly be reconciled with the fact that every human being over the age of three months is provided with a supply of the enzyme invertase whose sole function is the inversion of sucrose. It acts on no other food. The Almighty evidently intended us to eat sucrose.

The dextrose that gets into the blood of the portal vein resulting from the digestion of sugar or starch, is carried to the liver. If the blood sugar is below normal the dextrose passes through the liver to the general circulation to supply the heart, the muscles and other organs with fuel for their work. Any excess of dextrose is stored as a reserve in the liver in the form of glycogen or " animal starch." The muscles also have the ability to convert dextrose into glycogen and store it.

The conversion of the excess dextrose into liver glycogen, to be used by the body in the intervals between meals, is under the control of the chemical messenger, or " hormone," called " Insulin." Insulin is produced by the pancreas under nervous impulses received from the sugar regulating centre in the brain, as soon as the blood sugar content rises above normal, following a meal containing carbohydrates which form dextrose on digestion. Insulin has two main actions. It is essential for the conversion of the excess dextrose into glycogen in the liver, and it is necessary for enabling the tissues to burn the dextrose.

The regulation of the blood sugar content by the insulin is truly remarkable. The amount of food used daily by the body in the form of sugar is of the order of 100 times the amount of sugar in the blood, yet the quantity in the blood is normally held within about 20% either way.

In the disease diabetes there is a degeneration of the pancreas, which, in consequence, does not liberate insulin as needed. When carbohydrates are eaten there is an excess of sugar in the blood, because it cannot be converted by the liver into glycogen and because it cannot be properly burnt by the muscles. The kidneys respond to the high sugar content in the blood and remove it into the urine. This always occurs if the blood sugar exceeds 0·18%. Sugar in the urine is the most characteristic symptom of diabetes.

With the discovery of a method of preparing insulin from the pancreatic glands, " sweetbreads," of slaughtered oxen, the life of the diabetic patient changed from misery to hope. By taking injections of insulin the diabetic can now lead an almost normal life. His liver is enabled to turn dextrose into glycogen and his tissues can efficiently use the dextrose so necessary for any effort.

Diabetics are always liable to give themselves an overdose of insulin. If the blood contains too much insulin the liver converts too much dextrose into glycogen and the tissues burn up the sugar too rapidly, and a marked decrease in the blood sugar results. When the sugar content of the blood falls to about 0.06 or 0.05% the owner of the blood suffers from hunger pangs, exhaustion, tremor, sweating and then delirium and coma, possibly followed by death. The symptoms have sometimes been mistaken for extreme drunkenness. These symptoms are relieved, often in the most dramatic manner, by eating sucrose. All diabetics, therefore, carry a supply of sugar with them. Should they feel the onset of blood-sugar-shortage symptoms, the first of which is dizziness, they can, by eating sugar, abolish the symptoms in a few minutes.

THE UNIQUE VALUE OF SUCROSE AS A FOOD.

So far we have only discussed the fate of the dextrose that is absorbed into the blood after eating carbohydrates. (The galactose from milk sugar is trivial in amount and is converted into glycogen by the liver.) We are on less certain ground when we consider what happens to the lævulose. The greater part of it is probably converted into glycogen and stored in the liver. This glycogen is identical with that formed after taking dextrose and suffers the same fate—it is converted into blood sugar for use as required by the muscles and other organs.

Lævulose seems to be readily converted into dextrose by the lining of the intestine, by the liver and by the kidneys. But though the greater part of the lævulose is converted into dextrose or glycogen some gets into the general blood stream. The amount in the blood is rarely higher than 0.01% except in cases of severe disease of the liver. Modern methods of analysis have shown the presence of lævulose in blood drawn from a finger prick within five minutes of drinking a solution of sucrose.

An outstanding difference between dextrose and lævulose is the fact that the use by the body tissues of the lævulose seems to be independent of the presence of insulin. If you are exhausted as a result of lack of food or as the result of strenuous work, your blood sugar is at a low level and your efficiency is below par. If you now eat some dextrose your blood sugar will rise, but it cannot be used by your tissues and relieve your fatigue until the rise in blood sugar has reached or exceeded normal and has so resulted in the production of a supply of insulin into your blood. Since lævulose is used by the tissues without the intervention of insulin, the recovery from fatigue after taking sucrose is very much more rapid than after taking dextrose or any carbohydrate that does not yield lævulose on digestion. It can be demonstrated, that if a resting individual takes sucrose or lævulose the rise in the rate of use of sugar in the body

is much more rapid than after taking the same amount of dextrose. We have seen that dextrose does not pass straight into the system, and we can now state that even if it did it would not be available until it had produced a supply of insulin.

It is interesting to note that it is not possible to determine any difference in the rise of use of sugar in the tissues after taking sucrose from that of taking invert sugar, which might be called pre-digested sucrose. This indicates the remarkable ease and rapidity with which the sucrose is inverted and absorbed by the intestine.

Lævulose, obtained by eating sucrose, or obtained by eating invert sugar in the form of honey or golden syrup, is much superior to dextrose in relieving the symptoms that supervene after a period of starvation or prolonged muscular effort.

The almost magical effect of eating sucrose for the relief of fatigue is just now gradually emerging after being swamped by the flood of literature extolling the virtues of dextrose. But it has always been well known that before undergoing an ordeal—athletes before a race, mountaineers during a climb, hospital patients before an operation—sucrose is unequalled. The specific effect of sucrose has recently been the subject of practical test on golfers in America. It was found that the blood sugar falls during the round and that this results in decreased co-ordination of movement and of judgment. The eminent biochemist who has collaborated with the author in the foregoing physiological sections, and who is also a good golfer, says that he always eats some boiled sweets at the turn and that this prevents his putts and chip-shots deteriorating.

THE MEDICAL VALUE OF d-GLUCOSE.

There seems to be no biochemical or clinical evidence that dextrose is superior to cane sugar taken by the mouth by persons in health or ill-health. Such experiments as have been done indicate the reverse.

There is, probably, a psychological advantage in the prescription of " d-glucose " out of an elaborate package costing perhaps, shillings a pound and carrying the powerful juju " d- " in front of its name. A cheap simple remedy, such as granulated sugar, has no psychological value.

Some dextrose preparations are called " Glucose-D " or " Dextrose-D." The transfer of the juju to the rear and its elevation to a Capital Letter signify that vitamin " D " has been added. So far as is known at present vitamin D has no effect whatever on the utilisation of the sugars by the body. On the other hand, unless the body receives a proper supply of vitamin B_1, it cannot make complete use of the sugars.

Dextrose has one advantage over sucrose when patients suffering from sugar deficiency find the sweetness of cane sugar repugnant. The reason for this is largely due to the common medical practice of prescribing sugar in the form of sweet drinks. If sugar is prescribed in the solid form the sweetness difficulty largely disappears because most of the sugar does not dissolve in the saliva and is therefore not tasted.

THE USE OF GLUCOSE IN CONFECTIONERY.

Glucose is an essential ingredient in much confectionery. The extent to which it is used varies largely, and in many types of sweet it is used, not because it makes a better sweet, but because it makes a difficult slow process easy and quick.

Glucose has only from 20% to 30% of the sweetening power of cane sugar, and as the essential quality of a sweet is sweetness, too large a percentage of glucose is undesirable.

In the manufacture of boiled sweets pure cane sugar boiled with a little acid and flavouring for a certain time produces a fruit drop or acid tablet of maximum sweetness. But the temperature, time and acidity must be carefully controlled. By the addition of glucose the time of cooking can be reduced to seconds instead of minutes, while temperature and acidity are of much less importance.

In fondants and creams glucose is essential to preserve the smooth texture of the sweet. In caramels and some toffees glucose is needed to give the " chew " consistency.

The amount of glucose used in a few types of sweet lies within the following approximate limits :—

Boiled sweets	.	.	.	.	0 to 45%
Toffees .	.	.	.	.	0 to 40%
Fondants and creams	.	.	.	10 to 25%
Caramels	.	.	.	.	50%
Chocolate	.	.	.	.	0

CRYSTALS.

Many solid substances exist in the form known as crystals (from the Latin word crystallum—ice). Crystals of a substance have a certain definite form, and this form is always the same for any one particular substance. In view of the fact that crystals are the sugar refiner's finished product and that crystallisation is the refiner's principal process, it is remarkable how ignorant we sugar men are about crystals and their formation. There is a lot of

highly scientific knowledge about crystals, but very little of it has been turned to practical use.

A crystal is a symmetrical arrangement of the molecules of a substance built up in a regular pattern. The form of this pattern depends on the number and size and arrangement of the atoms in the molecules making up the substance. A substance having a very simple chemical composition of its molecules, such as common salt, whose molecules contain just one atom of chlorine and one atom of sodium, forms a very simple cube-like crystal. Sucrose, which is made up of large complex molecules containing 12 atoms of carbon, 22 atoms of hydrogen and 11 atoms of oxygen, forms a complicated crystal.

Crystals always form with flat faces. Some simple crystals have only four or six faces. The sucrose crystal has, normally, twelve faces. Each face in every crystal of a particular substance is always set at a certain unchanging angle with the neighbouring faces. The size of the various faces can vary quite a lot, but the angles between them are always constant. Different substances can be identified by the angles at which the crystal faces are set to each other.

If the molecules forming a crystal are looked upon as bricks and the crystal as being a symmetrical group of such bricks, then it will be clear that with ordinary square bricks the only shapes that can be built up will have their faces at right angles to each other. The shape can be fat and squat, long-shaped or flat, but the angles will always be 90°. If the molecules are shaped like pyramids then a number of different shapes can be built, but the angles between the faces must always be either 60° or 120°.

Crystals, if turned about certain imaginary pivots, will show an identical appearance if turned through a quarter-, third- or half-turn. The simple crystals will have several imaginary pivot lines. Such a pivot line is called an axis of symmetry. The simple crystals have more axes of symmetry than the more complex crystals. A cube has thirteen axes of symmetry ; three through the middle of the faces ; four diagonally through the corners and six from edge-centre to edge-centre. The main divisions into which crystals are classified are in accordance with the number of these axes of symmetry and their angular arrangement with each other.

THE SUCROSE CRYSTAL.

The sucrose crystal belongs to the " Monoclinic " group of crystals. (Two Greek words : monos—one, klinein—to incline.) There are three axes of symmetry in the sucrose crystal, two of these lie in the same plane and the other is at right angles to the

first pair. The first pair lie at an oblique angle to each other. Of the three axes it can therefore be said that one is inclined with reference to the others.

The sucrose crystal generally has twelve faces ; it may have more and it often has less. The angles between the faces of a crystalline substance are constant, but the sizes of the faces can vary. This is because the faces of a crystal do not grow at the same rate. We do not know why some faces grow quicker than others.
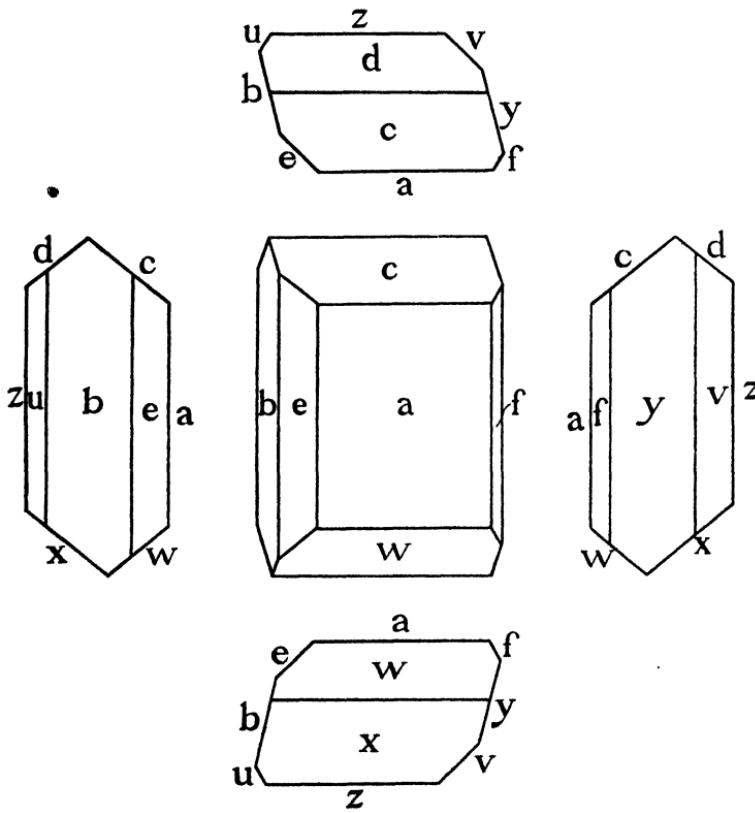
Fig. 85.
The Sucrose Crystal.

The speed of growth seems to be dependent on the conditions under which the crystal was grown and on the impurities in the solution from which it was grown. Individual faces which grow quicker than others eventually disappear. Apart from individual

quick-growing faces which disappear, we have good evidence that the growth of a sucrose crystal takes place principally on one end and one side.

Fig. 85 shows a sucrose crystal of perfect formation, and of the form in which we most often see it, with twelve faces. It is an enlarged picture of a crystal picked out of a sugar basin—it is one of Liverpool's coffee crystals and was just over ⅝ inch long. The faces that normally grow the quickest and eventually disappear are faces e, f, u and v. It is possible that faces d and w may disappear also. (Crystal faces are given all sorts of different and complicated letters and signs by different people. The lettering of the faces in Fig. 85 follows no scientific system ; it is simply a straightforward lettering starting from both ends of the alphabet.) The writer has never seen a very large sucrose crystal—that is one more than an inch long—with more than ten faces left. Large crystals usually have only eight faces, namely : a, z, b, y, c, x, d and w.

The reason for the disappearance of the fast-growing faces can be seen by looking at Fig. 86. This is intended to show successive layers of sucrose being deposited on a crystal with the faster growing faces receiving the addition of thicker layers than the slow-growing faces. As the angles between the faces cannot change, the fast-growing faces gradually fill up the spaces available for their growth. It is not suggested that Fig. 86 shows the real way in which a crystal grows. It is simply an illustration of how fast-growing faces will disappear.
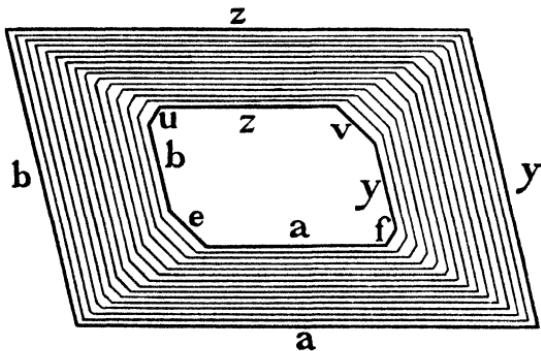
Fig. 86.
Disappearance of Fast-growing Crystal Faces.

The most important angle in the sucrose crystal is the angle of tilt of the whole crystal. This is the angle between faces a and b, or z and y. This angle is 103½° and is the characteristic angle of the sucrose crystal.

Apart from the disappearance of faces there can be a wide variation in shape. The ordinary crystals are generally about one-third longer than their width, but from the same skipping crystals can always be found that are twice as long as they are wide and sometimes the same length as their width. These variations cannot be accounted for with our present knowledge, but must be due to certain neighbouring faces growing faster than normal. Variations in growth may be due to impurities in the solution from which the abnormal crystals were grown. For example, raffinose, one of the sugars found in small quantities in the sugar beet, can cause sucrose to crystallise into long needle-like crystals. Sucrose obtained from the chemical processes for de-sugaring molasses often crystallises into thin flaky plates. In all these different shapes the form of the crystal is unchanged ; that is to say, the angles between the faces are always the same ; it is only the sizes of the faces that vary. We have often noticed that if the raw sugar crystals contain some special characteristic, this same characteristic reappears in the refined sugar crystals.

A damaged face grows quicker than a perfect face. A broken crystal quickly repairs itself as it grows. By the time the crystals in a pan are big enough to be clear to the naked eye, all the crystal fragments, which composed the dust used for shocking the pan, have become complete crystals.

When crystals dissolve in water the fast-growing faces are the quickest to dissolve. This has an interesting effect because if the fast-growing faces have disappeared they will quickly reappear when the crystal starts to dissolve. Fig. 86 can be looked upon as showing the reappearance of fast-dissolving faces.

HEAT OF SOLUTION AND HEAT OF CRYSTALLISATION.

When sugar is dissolved in water the solution gets cold because the sugar takes up " heat of solution " when it dissolves. This heat is very like latent heat and reappears when the sugar is crystallised out of the solution. Much of the steam that is supplied to the melter is required to provide this heat of solution.

When sugar is crystallised in the fine sugar pans all the heat of solution that was put in in the melter appears as " heat of crystallisation " and causes the steam consumption on the pans to be less than the amount which is necessary to boil the water off the liquors That this is really so is confirmed by the steam meter readings on the fine sugar pans.

The heat of solution and crystallisation of sucrose amounts to about 10 C.H.U. per pound at 50°C and to about 15 C.H.U. at 80°C.

LE CHATELLIER'S PRINCIPLE.

All substances tend to resist being made to change their state, by the giving up or taking in of energy in such a way as to make the change of state more difficult to accomplish. This is known as Le Chatellier's Principle and a good understanding of it clears up a lot of seeming mysteries.

Le Chatellier's principle enables us to predict the effects which will accompany a change of state if we know the conditions which promote the change. Thus, we know that heat promotes the change of solid sugar to dissolved sugar when the sugar is in the presence of water. We can predict that the sugar will resist solution by absorbing heat and thus cooling down and so making solution more difficult to accomplish. Again, we know that the cooling of a solution promotes the throwing out of crystals. We can therefore predict that the sugar will resist being made to crystallise by giving up heat and so warming the solution.

If an attempt is made to compress a gas—that is to make it occupy a smaller space, it resists the change by getting hotter which causes it to expand. It will therefore be necessary to use more pressure than would have been needed if it had not got hot. When a compressed gas is allowed to expand, we can predict that it will resist being caused to change its volume by absorbing heat and getting cooler so as to try to occupy a smaller space.

Occasionally a change of state occurs which apparently contradicts Le Chatellier's principle : for example, when caustic soda is dissolved in water a rise in temperature takes place although caustic is more soluble in hot water than in cold. This rise in temperature is caused because the solution of caustic in water is not just a simple dissolving but is accompanied by a chemical combination between the water and the caustic to form compounds called hydrates.

WATER OF CRYSTALLISATION.

Substances appear to like making themselves into crystals and seize every opportunity of doing so. Some molecules are of such a shape that they cannot fit themselves together to form a symmetrical crystalline structure. These substances often borrow molecules of water, the atoms of which fill up the crannies in the original molecule and so enable the molecules of the original substance plus the water molecules to build themselves up into crystalline form.

Some substances can form one kind of crystal by themselves and, by picking up some water can make crystals of quite a different form. Dextrose can be crystallised from a solution in alcohol into

fine needles. But when it is crystallised from a solution in water each dextrose molecule takes a water molecule into partnership and the molecules arrange themselves into six-sided scales, which cluster together into ugly masses which look like mildew.

One of the most interesting instances of crystals being formed by the taking up of molecules of water (called water of crystallisation) is plaster. Ordinary crystalline calcium sulphate is met with as a mineral in the form of gypsum or alabaster. It consists of a crystalline mass in which each molecule of calcium sulphate is associated with two molecules of water. When this gypsum is heated to between 150° and 200° C. three-quarters of the water of crystallisation is driven off, leaving two molecules of calcium sulphate associated with one molecule of water. It is no longer crystalline, but is a white rock-like mass which can be readily ground into a fine powder. It can be crystallised in this form under high pressure and temperature, and is sometimes found as a crystalline scale in high pressure boilers. This powdered mass of " burnt " gypsum is called " Plaster of Paris " or just " Plaster." If water is added to plaster powder each two molecules of calcium sulphate picks up three molecules of water to form crystals again. This is the reason why plaster " sets." It does not " dry " ; the water is taken into partnership to form dry hard crystals. If during the process of crystallisation the plaster cream is rubbed or stroked, it can be made to form long needle-like crystals which form excellent filter aids.

The plaster crystal belongs to the same structural group as the sucrose crystal, namely the monoclinic group, and if left to form without any rubbing is very like the sucrose crystal in appearance.

Some salts will take up ten or more molecules of water of crystallisation. Sucrose does not form crystals with water. The molecules of sucrose are of such a shape that they can build up a crystalline structure by themselves.

TWINNING AND ADHESION OF CRYSTALS.

Crystals sometimes grow as twins or triplets. That is to say, they grow outwards from one common face. This regular twinning is not often met with in sucrose crystals. But a similar effect is produced if two crystals lie with certain of their faces touching while they are growing. The faces in contact will adhere firmly and the crystals will grow as a twin. This is not strictly real twinning.

As the adhering faces of a twinned crystal cannot grow, some curious effects are produced. Fig. 87 shows the growth of such an adhering pair. It will be seen that eventually one crystal appears to have speared the other.

Crystal adhesion is the cause of our principal crystallisation enemy—rolled grain. If the crystals are kept in violent movement all the time they are growing they can never get the chance of adhering. This is why it is so important that the circulation in a pan should always be brisk. Rolling usually occurs when the circulation is very low, at a time when the evaporation must be cut down to prevent undue supersaturation. At such a time, too, the grains are very small and are more liable to stick together than when they are larger.
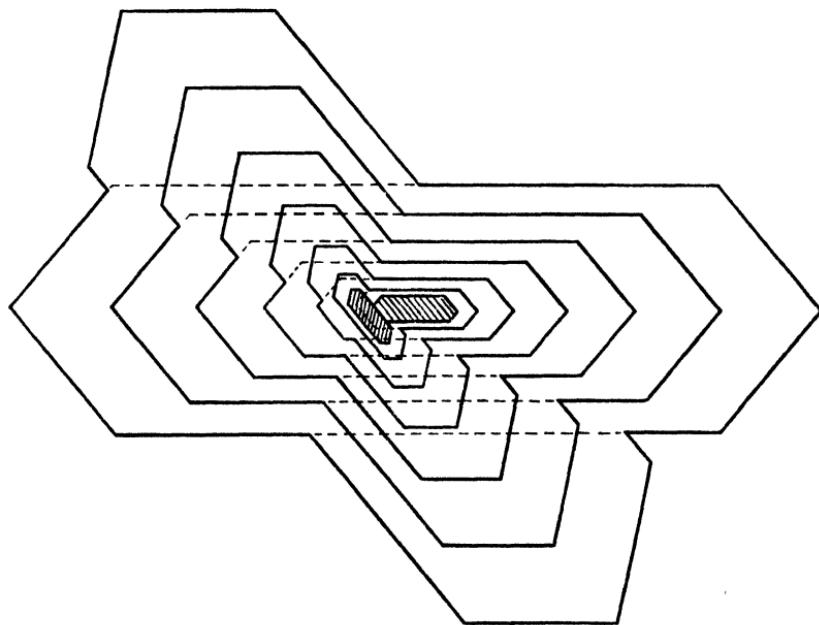
Fig. 87.
Growth of Adhering Crystals.

THE ADANT CUBE PROCESS.

A framework of cells or compartments is built up by slides which are rigidly held between two rings. To the bottom ring are fixed four columns, the top ends of which have threaded studs over which the top ring is placed. For additional support four intermediate columns are fitted which act as distance pieces. Both rings are fitted with slots into which the slides are fitted. The whole

framework is clamped together by shackles screwed on to the studs. Midway down the slides are lugs which serve the double purpose of preventing the slides from bending and separating the top half of the mould framework from the bottom half, so as to form two tiers of cells. The spaces round these lugs allow the massecuite to fill the lower tier of cells through the top tier. There are 112 cells in each tier, making 224 slabs of sugar from each " mould," as the framework is called.

The mould is placed inside a casing or " flask " which is fitted with a central circular column so that the cells are sealed on their inside and their outside and are only open at their tops. The masse is poured into the top of the mould. This operation must be done very carefully to prevent air being trapped, thus forming bubbles in the sugar slabs and perhaps preventing the masse filling the lower tier of cells before the top tier.

The moulds in their flasks are then set aside to cool for about sixteen hours. The cooling time depends on the temperature and circulation of the air in the cooling floor. During cooling the syrup surrounding the crystals reduces itself to near saturation point by growing on to the grain. This cements the grains together and reduces the viscosity of the syrup.

The mould, containing all the cells filled with moist sugar slabs, is then removed from the flask by means of a crane assisted by compressed air, and is placed in an underdriven centrifugal machine. The machine is run for some ten minutes and the syrup flies off edgewise through the slabs. When the " green " syrup has been thrown off, a saturated syrup or " clairce " is fed into the centre of the machine and washes, by displacement only, not by dissolving, the adhering syrup off the sugar. The clairce is the same as the liquor from which the masse was boiled.

When the clairce has been thrown off, the machine is stopped and the mould is lifted out with a crane. The shackles are unscrewed, the top ring lifted off and the mould is taken to pieces. This releases the slabs which are sufficiently hard to stand careful handling. The slabs are put on to a conveyor which takes them through the stoves where the last trace of water is driven off, causing the grains in the slab to be tightly cemented together.

The slabs are then passed through the cutting machines where they are advanced in a series of short steps between two sets of knives placed at right angles to each other, thus cutting the slab into cubes. The size of the cubes can be varied by adjusting the size of each step that the slab is advanced between each stroke of the knives.

The size of the slab (which varies in different parts of the mould) is approximately fifteen inches—the height of the cell, by eight and a half inches—the thickness of the sugar wall in the mould. The slabs are eleven-sixteenths of an inch thick.

The Adant process requires a truly vast plant ; but it produces a cube whose quality is quite unsurpassed in whiteness, sparkle, hardness and ease of dissolving in the tea-cup. This last quality is, surprisingly, of some importance. Some of the cheap methods of cube-making make a cube which, although too soft in its interior to stand rough transport, yet has a hard " rind " on it which makes it very slow to dissolve in the customer's cup.

One of the great advantages of the Adant process over others is that, owing to the long cooling process in mould, a very high yield of crystal sugar is obtained from one boiling—a yield that substantially exceeds the yield of an ordinary granulated boiling. This may be one of the reasons why Thames are able to make such high quality products with so little char.

Adant was a foreman in a Belgian refinery in Brussels and invented his process in 1890.

When Thames changed from the Langen process to the Adant in 1894, the refinery was shut down for a fortnight, the change-over made. and the new process started up with 240 fewer men.

THE HÜBNER CUBE PROCESS.

In the Hübner process as worked in Liverpool the massecuite from the pan is run direct into a special centrifugal machine which is also the mould. The basket of the machine is fitted with vertical aluminium division plates covered by a removable top. The machine is charged stationary with slightly too much masse. It is then run up to half speed for a minute or two to cause the masse to fill the cells between the division plates evenly without trapping air. The machine is then stopped and the excess sugar is scraped off the inside wall of the basket. The scrapings are melted to make the clairce. The machine is then run up to full speed. When the green syrup has been spun off, the clairce is added. The clairce is hot and saturated. As the slabs of sugar are cooler than the clairce the latter becomes supersaturated while passing through the slabs. This causes a certain amount of sugar to crystallise out of the clairce and to cement the crystals in the slab. The machine cycle is usually from fifteen to twenty minutes. The machine is stopped, the removable top is taken off, some of the division plates are taken out and the slabs removed. The slabs are then stoved and cut as in the Adant process.

The Hübner process is much quicker than the Adant process,

and the plant used is simple and comparatively cheap. It makes a good cube, but not quite so good as the Adant cube and there is no increase in yield over the yield obtained by an ordinary granulated boiling.

CRITICAL SPEED OF CENTRIFUGAL MACHINES.

When an unevenly charged centrifugal machine starts rotating the heavy side swings outwards because the centrifugal force must be greater on the heavy side because there is a greater weight of masse on that side. Now the heavy side is not alone and cannot act by itself. It has to pull the whole basket to one side. In order to pull the whole basket over, the heavy side must exert a considerable force and before the whole basket can move very much the heavy side will have moved some distance round the circle of rotation. The swing of the basket will always lag some distance behind the out of balance force. As the speed of rotation gets faster so will the lag in the swing of the basket get greater until, at a certain " critical " speed, the out of balance force due to the heavy side, will be exactly half a revolution in front of the swing of the basket. When this speed is reached the basket is much more comfortable. The out of balance force and the out of balance swing are now exactly opposite and the basket settles down and rotates round a new axis which passes through the centre of gravity of the out of balance basket. The heavy side will now be rotating round the smallest circle, while the light side will be rotating round the largest circle. In this condition the centrifugal force on all parts of the basket will be the same and the machine will run quite steadily and smoothly, although it will be running slightly out of truth. Below the critical speed the heavy side tries to rotate in a larger circle than the light side and tries to drag the whole basket with it. The machine is unstable and may swing badly. Above the critical speed the heavy side rotates in a smaller circle than the light side and the machine is stable and safe. Below the critical speed, as the basket increases in speed, the force due to the out of balance mass increases and the basket swing will get more and more pronounced.

The critical speed of a centrifugal machine is quite low and depends upon the length of the spindle and the restoring effect of the buffer. The longer the spindle the lower the critical speed. The stronger the buffer the higher the critical speed.

An unbalanced basket should be accelerated rapidly so that it can pass its critical speed as soon as possible before the swing has had time to become severe. Sometimes a man will switch the power off a swinging machine. The swing will not stop unless the machine is braked ; it may even increase.

SYRUP ON THE FACE OF A CENTRIFUGAL MACHINE.

It was stated on page 292 that at times syrup collects on the inner face of the wall of sugar in a centrifugal machine. This occurs when the grain is mixed so that small crystals block the crevices between the larger grains and block the holes in the cloth and prevent a very viscous syrup from getting away. Centrifugal force is proportional to the weight of a rotating body. Sugar crystals are heavier than syrups so that if a mixed grain blocks the holes in a machine cloth or packs the wall of sugar tight the syrup that cannot get away will find its way to the inner face and the crystals will get as far away from the centre as they can.

If an attempt is made to wash a basket that is in this condition the water will not go through the layer of syrup but will lie in a layer on the top of the syrup. Water is lighter than syrup and will have less centrifugal force acting on it. There is therefore no reason for it to penetrate the syrup layer. This condition may be dangerous, and many sugar men will have seen a centrifugal machine kick when an attempt is made to wash it with syrup on its face, and occasionally syrup or water may be thrown out 'of the machine. The explanation is as follows :—

A centrifugal machine is often unevenly charged so that one side of the basket is heavier than the other and the basket is out of balance. If the machine were carried in rigid bearings, the vibration caused by this lack of balance would soon wreck the machine. All modern machines are suspended so that they can rotate in an out of balance condition without transmitting vibration to the frame carrying the machine.

When an out of balance machine starts to rotate it starts revolving about the axis of its spindle, but as soon as it gets going the heavy side swings it outwards so that it is rotating eccentrically. The amount of this eccentric rotation is limited by the restraint of the buffer and the inertia of the basket. As the speed rises the critical speed is reached when the basket steadies and rotates round an axis which passes through the centre of gravity of the out of balance basket. The critical speed of a centrifugal machine has been discussed in the previous section. The condition above the critical speed is rather peculiar. The machine is quite stable, although rotating eccentrically. In order to be in balance the heavy side of the machine rotates in a smaller circle than the light side. In this state the higher centrifugal force due to the extra weight of the heavy side is exactly balanced by the reduced centrifugal force due to its rotating in a smaller circle.

Consider a machine running slightly out of truth owing to one part of the sugar wall being heavier than another, and the whole

of the inner face coated with a layer of syrup that cannot get away.
Let wash water now be added. The wash water will form a layer
on the top of the syrup. This wash water layer is being acted on by
centrifugal force and will therefore get as far away from the centre
of rotation as possible. Now the furthest side of the basket is the
light side. The water will therefore collect on the light side and will
make it heavier. At once the basket will rotate more truly and the
light side will come nearer the centre. The water will level itself
out instantly by rushing across the face towards the heavy side.
At once the basket will take up a new axis of rotation with the heavy
side nearest the centre. The water will at once rush across the face
back to the light side again. The machine may kick and water may
fly out. The whole thing is unstable and dangerous.

If the syrup on the face of a machine is in a thin film or is very
viscous it will be unable to flow rapidly across the face in the manner
just described. That is why machines can run in quite a stable
condition with molasses on the face.

CENTRIFUGAL FORCE.

We people in the sugar industry are particularly interested in
centrifugal force. It is upon this force that most of our pumps and
fans as well as one of our principal pieces of plant, the centrifugal
machine, work. Here is an attempt to explain centrifugal force.

All moving bodies move in a straight line unless some force is
applied to change their direction. A body, rotating round a point,
is trying all the time to move in a straight line. If a rotating body
breaks its connection with the centre round which it was rotating it
flies off straight in the direction in which it was moving at the
moment when the connection parted. The force which it exerts
on the connection holding it to the centre round which it is rotating
is called " centrifugal force." (Latin, centrum—centre, fugere—
flee from.) The force which the connection exerts in preventing it
from flying off and making it rotate in a circular path, is called the
" centripetal force." (Latin, centrum—centre, petere—move
towards.)

When a stone is whirled round on the end of a string, the
stone is trying to move in a straight line, and exerts a centrifugal
force on the string. This centrifugal force is balanced by the
centripetal force along the string, pulling the stone towards the
centre and forcing it to move in a circle. The stone is always
trying to go straight. The string is constantly pulling it towards
the centre. Therefore motion in a circle is motion in a straight line
combined with another motion towards the centre of the circle.

This motion towards the centre is not constant, but is ever

increasing. The speed of movement is changing. The measure of the rate of change of a moving body is called an acceleration.

In Fig. 88 is a circle. Point A is supposed to be moving in the direction of the arrow round the centre O. When point A has moved 20° round the circle it will have reached point B. If there were no centripetal force making it move in a circle, point A would move in a straight line, and would have moved to point B'. The length of the straight line AB' is the same as the length of the arc AB. Now if the point moves a further 20° round the circle, it will move from B to C and its comparable motion in a straight line would have been from B' to C'. The distance from B' to B is much less than half the distance from C' to C. These lengths are the imaginary paths along which the point would have to move in order to get from the straight path back on to the circular path.
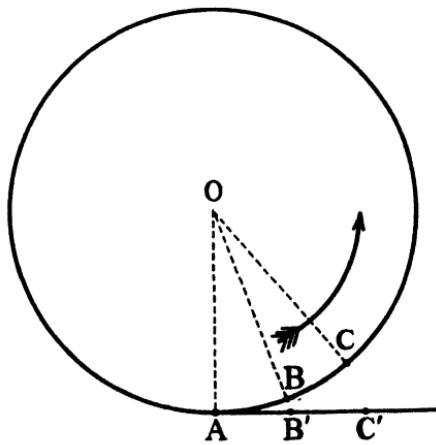
Fig. 88.
Motion in a Circle.

Let it be imagined that the rotating body is attached to the centre by an elastic connection, then assume that the body moved straight from A to B' and then was pulled with a jerk to B. If it had gone straight to C' and then been pulled on to the circular path to C, it would have to travel very much faster than before towards the centre to get to its position on the circle. This diagram shows that the further the body travelled in a straight line the more it will have to accelerate to get to its position on the circle. So that motion in a circle is an acceleration towards the centre.

An acceleration is expressed as so many feet per second per second, or (feet per second)². This seems to be still more confusing, but fortunately it is much easier to explain. Here is a little story

that explains quite simply this mysterious per second per second.

Ted has a motor bicycle that he bets will accelerate quicker than Tom's. Lest the police should get after them if they attempt an acceleration race, they decide to measure the acceleration of their motor bicycles separately. They agree to ride on each other's pillions and measure with a stop watch the rate of acceleration from 20 m.p.h. to 40 m.p.h. Ted's machine takes 4 seconds. Tom's takes 5 seconds. Ted wins the bet and says that his machine has an acceleration of 20 m.p.h. in 4 seconds, or 5 miles per hour per second. Now 5 miles per hour is the same as $7\frac{1}{3}$ feet per second. Instead of saying 5 miles per hour per second, Ted can say $7\frac{1}{3}$ feet per second per second.

Now the faster a rotating body is rotated, the greater is the centrifugal force. As rotation or motion in a circle is an acceleration and measured in feet per second per second or f.s.^{2}, it means that the centrifugal force will be proportional to the square of the speed around the circle. So here we have the first law governing centrifugal force :

F (the force) is proportional to V^2 where V is the peripheral speed.

Clearly the centrifugal force must be proportional to the mass of the body. So that :

F is proportional to the mass of the rotating body.

It is the fact that the body is moving in a circular path that causes centrifugal force. For the same peripheral speed the bigger the circle the smaller is the movement towards the centre. A very big circle is nearly a straight line, if only a small piece of it can be seen. It is clear that the centrifugal force will be proportional to the smallness of the circle, or, as the mathematicians prefer to say :

F is inversely proportional to R, the radius of rotation.

We have now dealt with all the things that can affect the rotating body, mass, speed and size of circle, so we can now write out the formula, first in words and then in symbols.

Centrifugal force is directly proportional to the mass of the rotating body and to the square of the peripheral speed, and inversely proportional to the radius of rotation.

$$F = \frac{MV^2}{R}$$

If we wish to use the weight of the body and to measure the force in pound units we must divide the mass by the acceleration

due to gravity, because the weight of a body is simply the force that gravity exerts upon its mass. The formula becomes :

$$F = \frac{WV^2}{Rg}$$

Now V the peripheral velocity is not a practical measure. We want to use the speed in revolutions per minute, both in pumps and in centrifugal machines. The peripheral speed in feet per second will be the length of the periphery multiplied by the revolutions per second, or the revolutions per minute divided by 60. The length of the periphery is the diameter of the circle of rotation (that is twice the radius or 2R) multiplied by π (the relation between the circumference and diameter of a circle). So that :

$$V = 2R \times \pi \times \frac{r.p.m.}{60}$$

Let us write N instead of r.p.m.

$$V = \frac{2 \times 22 \times RN}{7 \times 60} = \frac{RN}{9.55}$$

So we can now put this expression into our centrifugal force formula instead of V, and we can put in the value of g = 32·2, and we get :

$$F = \frac{WR^2N^2}{R \times 32.2 \times 9.55^2} = \frac{WRN^2}{2935}$$

As the diameter is usually the more convenient measure of the size of the circle of rotation we write D for R and divide by 2. So :

$$F = \frac{WDN^2}{5870}$$

We can now work out the centrifugal forces that each of our different types of centrifugal machines give to 1 lb. of sugar—that is W = 1.

Basket Diameter D		Speed r.p.m. N	$\dfrac{WDN^2}{5870}$ F	Proportional Centrifugal Force.
Inch.	Feet.			
48	4·0	750	383	1·00
54	4·5	750	431	1·13
40	3·33	1,200	818	2·14
40	3·33	1,600	1,450	3·78

LOSS DUE TO HEATING EFFECT OF ELECTRICITY.

There may be some confusion regarding the heating effect of an electric current. It was stated in Chapter 8., page 126 that

the heating effect is proportional to the resistance of the circuit and to the square of the current. That is to say, the heating effect is C^2R. When we go into a shop to ask the price and particulars of that nice-looking radiator in the window, we do not ask the salesman what its C^2R is. Such a question would flummox him, but he would give us the right answer if we asked him its rating in watts. In an electric radiator the whole of the electrical energy is turned into heat, and C^2R is equal to the watts flowing in the radiator circuit. Actually C^2R is another way of writing watts. Let us write it out :—

$$C^2R = C \times (C \times R).$$

From Ohm's law (page 124) we know that $(C \times R) = V$, so we can write V instead of $(C \times R)$.

$$C^2R = C \times (C \times R) = C \times V = \text{watts}.$$

Why therefore can we not say that the heating effect is equal to the watts in the circuit ? We can, whenever the current is flowing without interference through a simple circuit such as a radiator.

When a current flows in a motor armature or a stator winding Ohm's law does not apply, except when the armature or rotor is stationary, because the back-generated voltage or back-induced voltage (pages 156, 162) is opposing the input voltage. Let us assume that a motor has a resistance of 1 ohm and is supplied with a current at a pressure of 100 volts. If the motor is stationary a current of 100 amperes will flow. As the motor is doing no work it cannot be using any power and all the current will go in heat. So that the watts will be equal to the heating effect.

$$\text{Watts} = 100 \times 100 = 10,000$$

$$C^2R = 100 \times 100 \times 1 = 10,000$$

Now assume that the motor is running at full speed at full load. The amperes will now be say 10.

$$\text{Watts} = 10 \times 100 = 1,000$$

$$C^2R = 10 \times 10 \times 1 = 100$$

So that 100 watts are going in heat and 900 are going in power.

Take the case of a long distance transmission line. The power flowing along it may be thousands of kilowatts, but the heat loss is trifling and can be measured by C^2R where R is the resistance of the line.

Actually C^2R is the measure of the watts actually dissipated in forcing the current through the wire of the transmission line or

motor armature. If it were possible or practicable to measure the actual voltage drop across the transmission line or motor armature then the voltage drop multiplied by the current would be found to be equal to C^2R.

Take the case of the motor just considered : if the current flowing is 10 amperes and the resistance is 1 ohm the voltage necessary to drive the current through must be 10 volts. As the input voltage is 100 this means that the back-generated voltage must be 90 volts. So that the watts used to drive the current through the motor are : $10 \times 10 = 100$; and $C^2R = 10 \times 10 \times 1 = 100$. So that the actual watts needed for forcing the current through is equal to C^2R and is, of course, all dissipated as heat.

As it is often impossible, or at least impracticable to measure the actual voltage used in forcing the current along a line or through a motor, C^2R gives us an exact measure of the heat loss due to this useless power dissipation.

Text-books on electricity always stress the fact that current flowing in wires should be reduced as low as possible in order to reduce the C^2R loss and imply that this is the reason for the transmission of electric power by very high voltage. What is really meant is that unless the voltage is high the size and cost of the wires is so great, if they have to carry a huge current, that the wires would be skimped with a result that their resistance would be increased. This would necessitate a higher voltage to drive the current through with a consequent increase in watts and therefore in C^2R. There is no heat loss saved in the British grid by using a half inch wire at 132,000 volts against using a great rod of copper fifteen feet in diameter carrying current at 1 volt. The high voltage is simply a matter of cost and practical convenience. Three half inch wires are practical and cheap. Three wires each the size of a railway tunnel are clearly fantastic.

In the case of an alternating current with a low lagging power factor (see page 169) the heating effect of the amperes flowing in the circuit is independent of the power in the circuit—some of the current is " wattless." It can and does produce a heat loss which can be measured by taking the C^2R.

THE VOLTAGE IN A THREE-PHASE CIRCUIT.

As explained on pages 130, 141 in Chapter 7., the simultaneous voltage of all three phases is always zero. This enables one end of each of the phase coils to be connected to a common point through which no current will flow. The other ends of the phase coils are connected to the supply lines. This arrangement is called star connection and is shown in Fig. 89.

Now the line voltage across AB, BC or AC is clearly not the
same as the voltage across each phase coil, AD, BD or CD. The
voltage across AB is the difference of potential between the ends
of the coils AD and BD. If the voltage in AD is at a maximum the
voltage in BD will be at a lower value in the opposite direction.
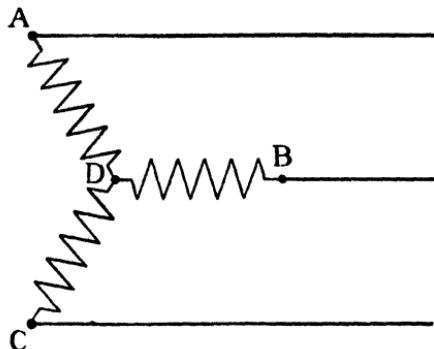
Fig. 89.
Three-phase Star Connection.

Clearly the difference of potential will be the combined effect of
both phases and will be greater than the voltage in a single phase
coil. We can take our three supply wires and connect them to a
machine in such a way that each coil in the machine receives line
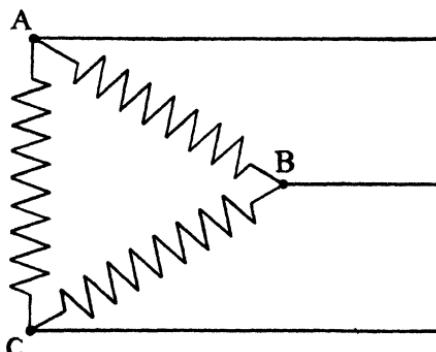
Fig. 90.
Three-phase Delta Connection.

voltage instead of phase voltage. This arrangement is called Delta
connection and is shown in Fig. 90, which is drawn to the same scale
as Fig. 89.

We want to know the relation between the voltage across AD and the voltage across AB.
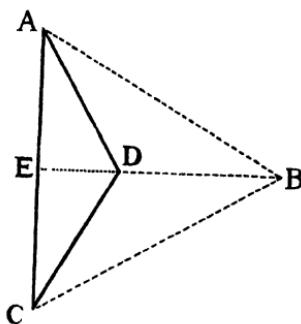
Fig. 91.
Star-Delta Vector Diagram.

Fig. 91 is what is called a vector diagram, in which DA, DB and DC are voltage vectors for each phase in star connection, and AC, AB and BC are the voltage vectors in delta connection. In a vector diagram each line is proportional to the quantity, force or velocity that it represents and is drawn in the direction in which it acts. So that the line AC is the vector for the line voltage resulting from the combined effect of the two phase-voltages represented by the vector lines DA and DC. The relation between the lengths of the lines DA and AC will be the relation between the voltages represented by these lines. The relative lengths of these lines can be found by simple mathematical means.

By trigonometry : $AC = \dfrac{DA \; \sin D}{\sin C} = DA \times \sqrt{3}$

By geometry : $DE = \dfrac{DA}{2}$ and $AE = \dfrac{AC}{2}$

$$\left(\frac{AC}{2}\right)^2 = DA^2 - \left(\frac{DA}{2}\right)^2$$

$$AC = DA \times \sqrt{3}$$

So that : Line or Delta Voltage = Star or Phase Voltage $\times \sqrt{3}$.

Star or Phase Voltage $= \dfrac{\text{Line or Delta Voltage}}{\sqrt{3}}$

$$\sqrt{3} = 1{\cdot}73 \text{ and } \frac{1}{\sqrt{3}} = {\cdot}58$$

So that :   Line or Delta Voltage = Star or Phase Voltage × 1·73

Star or Phase Voltage = Line or Delta Voltage × ·58

Line or Delta Voltage.	Star or Phase Voltage.
110	67
220	128
440	255

PROPERTIES OF PURE SUCROSE SOLUTIONS.

Figures 92 and 93 on pages 380 & 381, are alignment charts and show the common properties of pure sucrose solutions. The scales on these charts were calculated by Philip Lyle from the latest available data (1939). For example, for solubilities, Grut's figures were used—not Herzfeld's, and for B.P.E. Bucharov and Spengler's figures were used. Some of the scales are not mathematically exact—but the errors are so small that the charts are quite accurate enough for all practical purposes.

The charts are for pure sucrose solutions—things that we never meet in the refinery. No charts or tables can be made for impure syrups or molasses because their properties have not yet been measured with sufficient accuracy. Fortunately for liquors and fairly pure syrups we can use the properties of pure solutions without going far enough astray to matter.

To use an alignment chart the values of any two of the properties shown on the chart are joined by a straight line (either by using a strip of celluloid with a fine line scratched on it, or by holding a fine thread—which must be held taut—across the chart.) The other values can be read off where the line cuts their scales.

Figure 92 will give us the following information about a solution whose Brix and Temperature are known :—

> The Supersaturation Co-efficient.
> The Vacuum at which the solution will boil.
> The Temperature at which water will boil at the vacuum in question, which gives us the B.P.E.

In Fig. 93, if we know the Brix and Temperature of the solution the chart gives the following other properties :—

> Viscosity.
> Specific Heat of the Solution.
> The Self-Evaporation in pounds of water flashed off
>   1,000 pounds of solution for each degree by which the

temperature is reduced by subjecting the solution to vacuum.

The Total Heat in the Solution. That is to say the amount of heat that would have to be added to water at 0° C. and sugar at 0° C. to make the sugar dissolve in the water and bring the solution to the temperature in question.

Example :—We have a liquor of 80° Brix at a temperature of 70° C. At what vacuum will this solution boil and what will be the B.P.E. ?

In Fig. 92 join the Brix to the temperature on the two outer scales. The straight line cuts the vacuum scale at 23·4 inches and the water boiling scale at 62·1° C. The B.P.E. is therefore 7·9° C.

Example :—At what Brix would a solution at 80° C. be saturated ?

In Fig. 92 join the saturation point 1·0 on the supersaturation scale, with 80° C. on the temperature scale and the straight line cuts the Brix scale at 79·3°.

Example :—If we have a solution of 80° Brix at 70° C. what will be its Specific heat ?

Join the Brix to the temperature on the two outer scales of Fig. 93 and the straight line cuts the specific heat scale at 0·621.

Example :—Suppose a granulated masse is at a temperature of 70° C. with its syrup at a supersaturation of 1·1, to what temperature must it be raised to bring it to saturation and what reduction in viscosity would this produce ?

In Fig. 92 join 1·1 on the supersaturation scale to 70° C. on the temperature scale and the straight line cuts the Brix scale at 78·5°. Still on Fig. 92, move the line so that it cuts 78·5° on the Brix scale and passes through 1·0 on the supersaturation scale and the line passes through the temperature scale at 77° C. : so that the masse must be raised to 77° C. to bring it down to saturation.

In Fig. 93 we find that by joining the Brix of 78·5 to the two temperatures 70° C. and 77° C. the viscosity has been reduced from 1·5 to 0·95.

Example :—Suppose we have a brown liquor of 68° Brix at a temperature of 87° C. and wish to cool this to 73° C. by self-evaporation. What will be the Brix of the cooled liquor and what vacuum will be needed in the cooler-evaporator ?
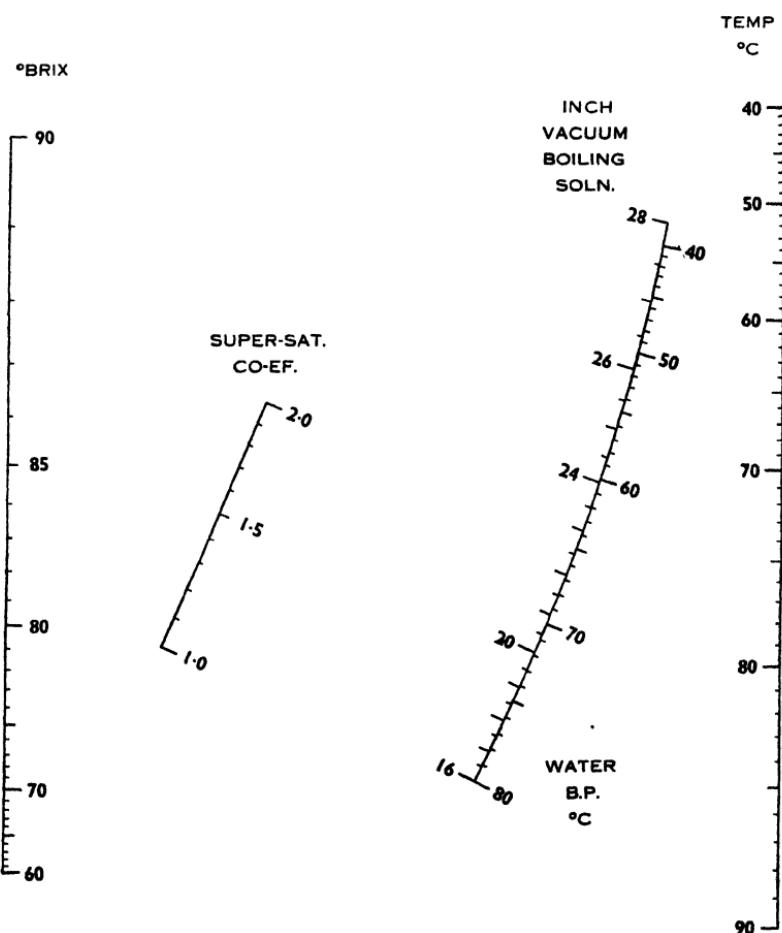
Fig. 92.
*Solubility, Supersaturation, Boiling Pressure and B.P.E. of Pure
Sucrose Solutions.*
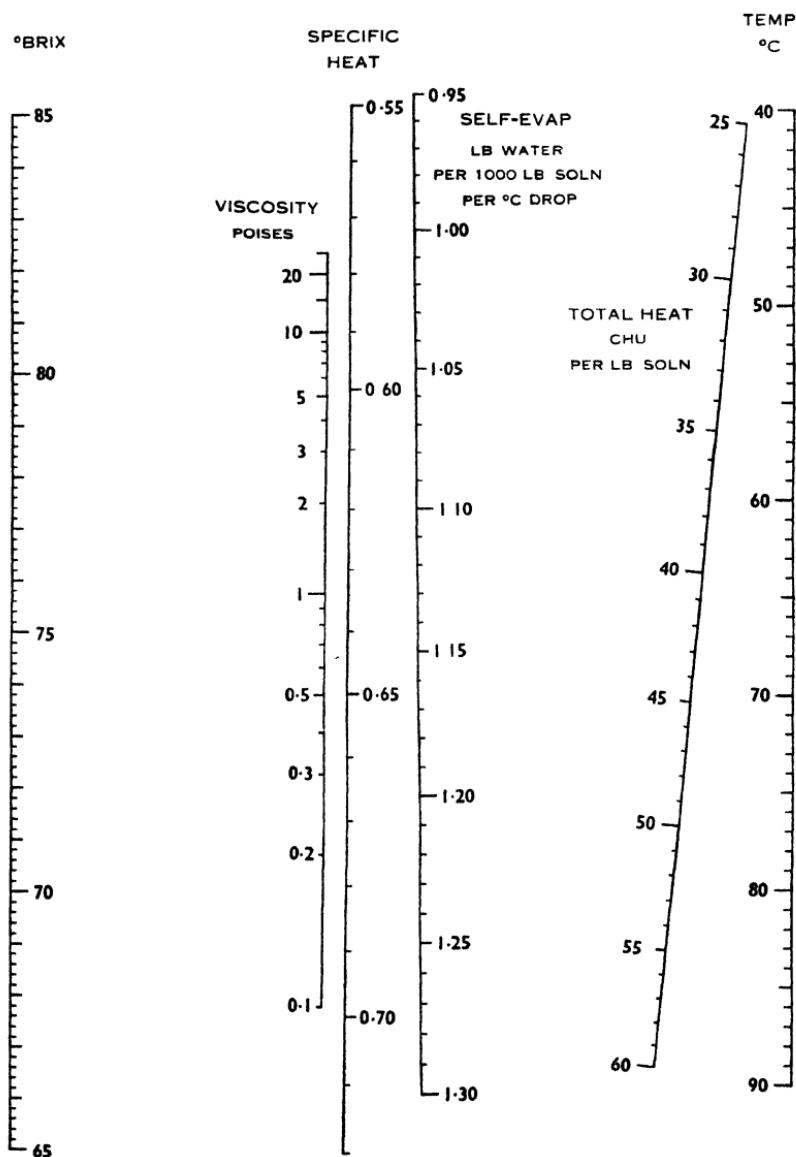
Fig. 93.
Viscosity, Specific Heat, Self-Evaporation and Total Heat of Pure Sucrose Solutions.

Join 68° Brix in Fig. 93 with the temperature of 87° C. The line cuts the self-evaporation scale at 1·273 lb. per 1,000 lb. per °C. drop. We are going to drop the temperature 14° so that 14 × 1·273 lb. of water will be flashed off 1,000 lb. of the liquor. 1,000 lb. liquor at 68° Brix contains 680 lb. sugar in 320 lb. water. After flash the 680 lb. sugar will be dissolved in 320 — 14 × 1·273 = 302·2 lb. water. The total weight of the solution will be ·9822 lb. so that the Brix will be 68 divided by ·9822 = 69·23° Brix. An increase of 1·23° Brix.

Set the temperature at which the cooler-evaporator is to work, namely, 73° C. on Fig. 92 against the new Brix of 69·23° and the line cuts the vacuum scale at 21·3 inches.

Example :—How much heat must be supplied to the melter to make a liquor of 70° Brix at 70° C. from washed sugar at 40° C. and water at 90° C. ?

Join 70° Brix to 70° C. on the outer scales of Fig. 93 and the total heat of the liquor is shown as 45·8 C.H.U. per lb.

Now 1 lb. liquor contains 0·7 lb. sugar and 0·3 lb. water. 0·3 lb. of water at 90° C. contains 0·3 × 90 × 1·0 = 27 C.H.U. Table XIII. tells us that 0·7 lb. sugar at 40° C. will contain 0·7 × 40 × 0·311 = 7·6 C.H.U. So the ingredients of the liquor contained 27 + 7·6 = 34·6   C.H.U.   We must therefore add 45·8 — 34·6 = 11·2 C.H.U. to each pound of melter liquor.

TABLE XIII.

SPECIFIC HEAT OF PURE SUCROSE CRYSTALS.

Temp. °C.	Specific Heat.
0	0·277
10	0·286
20	0·294
30	0·303
40	0·311
50	0·320
60	0·328
70	0·337
80	0·345
90	0·354
100	0·362

PROPERTIES OF PURE SUCROSE CRYSTALS.

Specific Gravity   –   –   –   1·58
Melting Point   –   –   –   160° C.
Refractive Index   –   –   –   1·55
Calorific Value per lb.   –   –   {1794 Calories
                                      {3955 C.H.U.

TABLE XIV.

SPECIFIC GRAVITY OF PURE SUCROSE [SOLUTIONS.

Specific	*Per cent. Sucrose at temperatures*			
Gravity	20°C	40°C	60°C	80°C
1·00	0·5	1·9	4·2	7·6
1·02	5·5	7·0	9·3	12·5
1·04	10·5	11·9	14·2	17·5
1·06	15·2	16·7	18·9	22·1
1·08	19·8	21·3	23·5	26·6
1·10	24·2	25·8	27·9	30·9
1·12	28·5	30·1	32·2	35·1
1·14	32·7	34·3	36·4	39·2
1·16	36·8	38·4	40·4	43·2
1·18	40·7	42·3	44·3	47·0
1·20	44·5	46·2	48·1	50·7
1·22	48·3	49·9	51·8	54·4
1·24	51·9	53·5	55·5	58·0
1·26	55·4	57·1	59·0	61·4
1·28	58·9	60·6	62·4	64·8
1·30	62·3	63·9	65·8	68·2
1·32	65·6	67·3	69·1	71·4
1·34	68·9	70·5	72·3	74·6
1·36	72·0	73·7	75·5	77·6
1·38	75·2	76·8	78·6	80·7

BOOKS ON SUGAR.

There are a number of books on sugar ; some of them excellent. For those who want to learn more about sugar and sugar technology there are four outstanding books.

"Sugar," by Geoffrey Fairrie, covers the whole sugar industry. It is very easy reading and gives simple descriptions of everything connected with sugar. It is a first-class book and should be read before attempting to read the heavier books.

"Cane Sugar," by Noel Deer, is probably the best book on sugar ever written, but it contains no mention of refining. It deals not only with technical and chemical problems, but with engineering and plant design, heat economy, etc. The reader should not be put off by pages of mathematics. These can be skipped by the non-mathematical reader. There is a mass of good reading in between the more technical matter.

"Cane Sugar and its Manufacture," by H. C. Prinsen Geerligs, is a purely technical book. Plant design is not treated at all, and there are no illustrations. On the other hand, there is very little mathematics. Every sentence in the book is worth reading. Sugar refining is not dealt with.

"The Elements of Sugar Refining" by Bardorf and Ball, is the only book in English on sugar refining. It is an excellent book, only marred by the use of abbreviations, such as FGS, ExB, etc., which those unaccustomed to their meaning find difficult to memorise.

"Sugar," by Newlands, is now out of date, but is interesting to all "Plaistovians" because it describes and illustrates (page 568) the Plaistow Wharf Refinery as it was originally built in 1882.

There are a number of other books ; some good ; one, at least, not so good. But by the time the seeker after learning has read the four books named above he will be in a position to discriminate so that he can safely read anything he can find without getting false impressions.

> . . . *Last scene of all,*
> *That ends this strange eventful history.*
> SHAKESPEARE—As you Like it—1599.

TECHNOLOGY FOR SUGAR REFINERY WORKERS.

Please make the following corrections in the Index.

There are some other places where the reference is wrong by one page. These are not of sufficient importance to warrant correction.

INDEX.

. . index-learning turns no student pale,
Yet holds the eel of science by the tail.

POPE—The Dunciad—1728

Every dash (—) stands for a word in the line preceding it. Where a pair of hyphened words first appear together, one dash is used to represent the hyphened pair. Where a hyphen connects two words after the first appearance of the first word, two dashes are used. Where confusion might arise when two words mean different things when their order is reversed, hyphens have been inserted; e.g. Sugar, cane, *see* Cane-sugar; Cane, sugar, *see* Sugar-cane.